ALLOYS

AMALGAMS

SOLDERS

ANALYSIS

COLORING

RECOVERY OF WASTE METALS

BRANNT

THE METALLIC ALLOYS

THE

METALLIC ALLOYS.

A PRACTICAL GUIDE

FOR THE

MANUFACTURE OF ALL KINDS OF ALLOYS, AMALGAMS, AND SOLDERS, USED BY METAL-WORKERS;

TOGETHER WITH

THEIR CHEMICAL AND PHYSICAL PROPERTIES AND THEIR APPLICATION IN THE ARTS AND THE INDUSTRIES;

WITH AN

APPENDIX ON THE COLORING OF ALLOYS AND THE RECOVERY OF WASTE METALS.

EDITED BY

WILLIAM T. BRANNT,

EDITOR OF THE "TECHNO-CHEMICAL RECEIPT BOOK," AND "THE METAL WORKER'S HANDY BOOK."

ILLUSTRATED BY FORTY-FIVE ENGRAVINGS.

THIRD EDITION, THOROUGHLY REVISED AND ENLARGED.

PHILADELPHIA:
HENRY CAREY BAIRD & CO.,
INDUSTRIAL PUBLISHERS, BOOKSELLERS AND IMPORTERS,
810 WALNUT STREET.
1908.

LIBRARY of CONGRESS
One Copy Received
APR 20 1908
Copyright Entry
Apr 14 1908
CLASS A XXc. No.
204265
COPY B.

COPYRIGHT, BY
HENRY CAREY BAIRD & CO.,
1908.

PRINTED AT THE
WICKERSHAM PRINTING HOUSE,
111 EAST CHESTNUT STREET,
LANCASTER, PA., U. S. A.

PREFACE TO THE THIRD EDITION.

THE third edition of "The Metallic Alloys," now presented to the public, has been thoroughly revised and brought up to date. No essential portions of the other editions have been omitted, but considerable new matter, including the composition of a number of new alloys, has been added, and some portions have been entirely rewritten.

While the general arrangement of the text has been preserved, a few changes have been made so as to bring allied subjects more closely together, and the principal iron-alloys, among which vanadium-steel now occupies a prominent position, it being of great importance particularly for the automobile industry, have been brought together in a separate chapter.

Like the previous editions the book has been provided with such a copious table of contents and very full index, as to render reference to any subject prompt and easy.

W. T. B.

PHILADELPHIA, *April 15th, 1908.*

PREFACE TO THE SECOND EDITION.

The rapid sale of the first edition of "The Metallic Alloys," and the constant demand for it, are the best evidence that no apology is necessary for presenting a second edition.

The present volume is designed to be an improvement on the former. Mistakes have been corrected wherever detected, and in some instances the order of treatment of different parts has been revised so as to bring them into strict logical sequence. Chapters have been added, and the physical and chemical relations of the metals, as well as the special properties of the alloys, have been more fully treated. But, whilst the scope of the work has been enlarged, it has been endeavored to preserve its popular character so that it will be easily understood by those readers who have not made Metallurgy and its kindred Arts subjects of special study, and be of practical utility to them. In short, the object aimed at has been to present a reliable guide to all persons professionally interested in the manufacture and use of alloys, amalgams and solders.

Great care has been exercised in selecting only such processes and formulas as have stood the test in practice; and many journals, both foreign and domestic, have been searched for the purpose of gathering together the results of recent experiments by acknowledged authorities. Various text-books and encyclopædias, previously published in

this country and abroad, have also been freely consulted, with the object of rendering the present work as complete as possible. In particular the editor desires to express his indebtedness to the following works: Thurston, *A Treatise on Brasses, Bronzes and Other Alloys;* Krupp, *Die Legirungen;* Ledebur, *Die Metallverarbeitung auf chemisch-physikalischem Wege;* Muspratt's *Theoretische, praktische und analytische Chemie.*

Finally, it remains only to be stated that the publishers have spared no expense in the mechanical production of the book; and, as is their universal custom, have caused it to be provided with a copious table of contents, and a very full index, which will add additional value by rendering any subject in it easy and prompt of reference.

W. T. B.

PHILADELPHIA, *July 4th, 1896.*

CONTENTS.

CHAPTER I.

INTRODUCTION.

PAGE

Constitution of technically-prepared metals; Explanation of the terms alloy and amalgam; Change in the properties of a metal by alloying. . . 1

Earliest historical data in reference to the compounding of metals; Early general use of brass; Preparation of alloys by the Greeks; Early alloying of the noble metals 2

Bronze the earliest product of mixed metals; Historical order of alloys; Use of amalgams by the Greeks and Arabs; Early application of fire-gilding to metallic articles; Alloys known up to the commencement of the reign of Charlemagne; Development of chemistry principally due to the Arabs. 3

Influence of alchemy upon modern chemistry; Use of mixtures of metals in the middle ages; Coinage in the middle ages; Advance in the extraction of metals from minerals 4

Present knowledge of metals; The science of metallic alloys a wide field for the activity of the chemist; Facts which might indicate that an alloy is a chemical combination 5

Processes which take place in making solutions; Variations in the physical properties of ordinary solutions from those of their constituents. . . 6

Concentration of the content of salt in sea-water; The properties of alloys not a certain proof of their character as chemical combinations; Crystallization of alloys; Not every alloy a pure chemical combination . . . 7

Formation of actual chemical combinations of separate constituents of the alloys; Constitution of alloys in a fixed state; Solutions of metalloids in metals 8

Boundary between metals and non-metals; Conception of the term alloy; Alloying power of metals; Formation of alloys 9

Production of alloys; Development and consumption of heat in combining the constituents to alloys 10

Exceptions to the rule according to which alloys are formed. . . . 11

CHAPTER II.

PHYSICAL AND CHEMICAL RELATIONS OF THE METALS.

Necessity of a knowledge of the elements to be alloyed; Division of the elements into metals and non-metals or metalloids; Characteristics and peculiar properties of metals 12

PAGE

Impossibility of sharply defining the meaning of the words metals and non-metals; Physical relations of the metals: What is generally understood by the term metal 13

Malleability of metals; Difference in the ductility of metals; Opacity of metals; Fusibility of metals; Table of melting temperatures corresponding to different colors 14

Points in which all the metals agree; Chemical relations of the metals; Affinity for oxygen 15

Division of metals into base and noble; Heavy and light metals; Properties of light metals 16

Metals of the alkalies; Metals of the alkaline earths; Metals of the earths . 17

Decomposition of water by the light metals; Division of the heavy metals into four groups 18

Influence of non-metallic bodies upon metals 19

Illustrations of the influence of non-metallic bodies upon iron; Influence of carbon, sulphur and phosphorus 20

Definition of a chemical combination; Formation of symbols . . . 21

Table of elements with their symbols and atomic weights; Chemical formulæ. 22

CHAPTER III.

SPECIAL PROPERTIES OF THE METALS.

Metals of the alkalies; Potassium; Sodium 23

Lithium; Metals of the alkaline earths; Metals of the earths proper; Aluminium 24

Specific heat and conductivity of heat of aluminium; Electric conductivity of aluminum 25

Distribution of aluminium; Former preparation of aluminium; The principle of reduction by electrolysis 26

Analyses of commercial aluminium; Effect of iron in aluminium . . . 27

Magnesium; Isolation of magnesium, in 1808, by Davy; Properties of magnesium 28

Difficulties in preparing magnesium alloys; Magnesium alloys and amalgams 29

Heavy metals; Iron group; Iron; Native iron 30

Iron considered as an alloy with carbon; Preparation of chemically pure iron 31

Oxidation of iron; Alloying power of iron 32

Technical importance of iron alloys; Manganese 33

First extraction of metallic manganese; Alloying power of manganese; Cobalt; Principal naturally occurring compounds of cobalt; Properties of the pure metal 34

Alloying power of cobalt; Nickel; Discovery of nickel; Occurrence of nickel ores; Commercial nickel; Properties of nickel 35

Dr. Fleitman's process of refining and toughening nickel; Alloying power of nickel 36

Early use of nickel for coins; The subject of nickel-steel alloys first called

PAGE

attention to by Mr. James Riley, of Glasgow; Nickel-steel armor-plates; Chromium, and its properties 37

Uranium, its occurrence and properties; Zinc group; Zinc; Occurrence of zinc ores; First mention of metallic zinc 38

Commencement of the manufacture of zinc in Germany, and in England; Manufacture of zinc in the United States; Properties of metallic zinc; Zinc white 39

Alloying power of zinc; Cadmium, its occurrence and discovery; Manner of obtaining pure metallic cadmium 40

Properties and alloying power of cadmium 41

Indium, and its properties; Gallium, its discovery and properties; Tungsten group; Tungsten 42

Principal native compounds of tungsten; Preparation and properties of metallic tungsten; Molybdenum; Vanadium; Best known vanadium minerals. 43

Preparation of vanadium by the electric method; Properties and alloying power of vanadium 44

Tin group; Tin; Occurrence of tin ore; Table of analyses of commercial tin; Properties of chemically pure tin 45

The "tin-cry"; Putty powder; Forms of unmanufactured tin; Alloying power of tin; Titanium and its occurrence; Effect of titanium on iron . 46

Manner of obtaining metallic titanium; Moissan and Violle's electric furnace, described and illustrated 47

Alloying power of titanium; Titanium bronze; Aluminium-titanium alloys . 48

Rickard's investigations of the behavior of titaniferous aluminium towards various liquids 49

Electric furnace of the Deutsche Gold und Silberscheideanstalt of Frankfort-on-the-Main, described and illustrated 50

Lead group; Lead; Properties of pure lead; Affinity of lead for oxygen . 51

Alloying power of lead; Thallium; Silver group; Copper, and its propeties . 52

Alloying power of copper; Mercury, and its properties 53

Alloying power of mercury; Amalgams; Silver; Occurrence and properties of silver 54

Gold group; Gold; Wide distribution of gold 55

Properties and alloying power of gold; Platinum, its occurrence and properties 56

Alloying power of platinum; Bismuth group; Bismuth, its occurrence, properties, and uses; Antimony, its occurrence and properties 57

Arsenic, its occurrence and properties 58

Definition of an alloy as generally understood; Changes in the properties of a metal by the addition of a non-metallic element; Sulphur, its occurrence and purification; Affinity of sulphur for metals: Characteristics of combinations of the metals with sulphur 59

Carbon: Wide distribution of carbon throughout nature; Crystallized forms of carbon; Solution of carbon in melted metals 60

Phosphorus; Effect of phosphorus upon metals; Phosphor-bronze . . . 61

PAGE

CHAPTER IV.

GENERAL PROPERTIES OF ALLOYS.

Changes which certain metals undergo by melting together or alloying; Liquation; The eutectic solution; Formation of ice in a common salt solution. 62
Separation of silver from a melted silver-copper alloy during cooling; The eutectic silver-copper alloy 63
Appearance of silver-copper alloys under the microscope, illustrated . . 64
Appearance of the eutectic silver-copper alloy under the microscope, illustrated 65
Behavior of alloys of lead and tin, and of lead and antimony in congealing; Definition of liquation 66
Prevention of liquation; Changes in the properties of an alloy by remelting and renewed cooling; Progress of cooling in the solidification of liquid metals and alloys; Variations in the composition due to liquation . . 67
Tendency of copper-tin alloys towards liquation; Tin stains; Composition of French pieces of ordnance 68
Tendency towards liquation of various alloys 69
Specific gravity; Variations in the actual and calculated specific gravities; Expansion and condensation of alloys; Sources of error in determining the specific gravity 70
Formula for calculating the specific gravity of an alloy; Determinations of the specific gravities of copper-tin alloys by Riche and Thurston . . . 71
Table of specific gravities of copper-tin alloys 73
Results of Riche experiments with copper-tin alloys 74
Table of specific gravities of copper-zinc alloys 76
Table of specific gravities of copper-silver alloys 77
Table of specific gravities of copper-gold alloys 78
Tables of specific gravities of silver-gold and lead gold alloys . . . 79
Tables of specific gravities of silver-lead and antimony-tin alloys . . . 80
Table of specific gravities of antimony-bismuth alloys 81
Table of specific gravities of antimony-lead alloys. 82
Tables of specific gravities of tin-cadmium and tin-bismuth alloys. . . 83
Table of specific gravities of tin-silver alloys. 84
Table of specific gravities of tin-lead alloys 85
Table of specific gravities of tin-gold alloys 86
Tables of specific gravities of cadmium-bismuth and cadmium-lead alloys . 87
Tables of specific gravities of bismuth-silver and bismuth-lead alloys . . 88
Table of specific gravities of bismuth-gold alloys 89
Table of specific gravities of tin-mercury alloys (tin amalgams) . . . 90
Table of specific gravities of lead-mercury alloys (lead amalgams); Division of alloys examined into three groups. 91
Alloys which plainly show contraction; Alloys which plainly show expansion; Alloys which do not show plainly either expansion or contraction . 92
Crystallization; Copper-tin alloys; Copper-zinc alloys 93
Antimony-zinc alloys; Gold-silver, lead-silver and silver-mercury alloys; Gold-tin alloys; Iron-tin alloys; Iron-manganese alloys; Importance of the crystallization of alloys 94

PAGE

Strength; Definition of strength: Law in regard to the influences exerted upon the strength of metals by alloying 95
Increase in the strength of copper by the addition of tin, or of aluminium . 96
Influence of an addition of zinc upon the strength of copper; Example of the increase in strength which can be brought about by alloying; Additional increase in strength by the addition of a third metal to an alloy consisting of two metals 97
Examples of such increase in strength 98
Steady increase in the limit of elasticity with the breaking strength; Thurston's investigations of the strength of copper-tin alloys 99
Measurement of the tenacity of alloys; Examination of aluminium-copper alloys, and of zinc-copper alloys with additions of aluminium . . . 100
Elongations of zinc-copper alloys; Hardness; Increase in hardness by alloying. 101
Method for determining the degree of hardness; Influence of the alloy upon the degree of hardness of the metals; Mode of decreasing the hardness of copper-tin alloys; Hardening of copper by the absorption of zinc . . 102
Hardening of gold and silver; Wear of copper-silver alloys by abrasion; Increase in the hardness of lead by alloying with antimony; Hardness of lead-tin alloys. and of zinc-tin alloys; Increase in the hardness of iron . 103
Flexibility or ductility; Conditions on which flexibility depends; Most flexible metals 104
Influence of temperature on flexibility; Diminution of flexibility by alloying. 105
Effect of various metals on flexibility; Exception to the rule according to which pure metals are more flexible than alloys 106
Casting capacity; Properties on which the casting capacity depends; Melting temperature; Lowering of the melting temperature by alloying illustrated by examples and diagrams 107
Melting temperatures of copper-zinc alloys 109
Reduction in the melting temperature by the addition of a third or fourth metal to an alloy 111
Rule applicable to the manufacture of very fusible alloys; Fluidity and its influence upon the casting capacity of alloys 112
Development of gases; Influence of the development of gases on the casting capacity; Prevention of the development of dissolved gases . . . 113
Origin of the gases 114
Means for stopping the development of gases; Shrinkage; Definition of shrinkage 115
Shrinkage of pure metals and of alloys; Conductivity for heat and electricity; Injury to the conducting power for electricity by alloying; Matthiessen's investigations 116
Conductivity of copper and zinc for heat and electricity; Influence of a foreign body on the conductivity 117
Color; Effect on the color of a metal by the addition of determined quantities of another; Diversity in color of the metals 118
Scale for colored alloys. 119

PAGE

Comparison of the scale of color of copper-tin and copper-zinc alloys; Coloring power of nickel 120

Coloring power of gold; Resistance to chemical influences; Practical importance of the resistance of alloys to chemical influences; Action of the atmosphere on alloys. 121

Reduction in the chemical action of a body by alloying a metal with another; Experiments of St. Claire Deville 122

Calvert and Johnson's investigations of the resistance of copper-tin and copper-zinc alloys to acids and salts; Influence of sea-water upon copper-zinc and copper-zinc-tin alloys. 123

Formation and analysis of patina; Action of chemical agents upon copper-silver and gold-silver alloys; Action of acids and salt solutions upon lead-tin alloys; Results of Knapp's investigations 125

R. Weber's experiments with lead-tin alloys; Composition of alloys for vessels intended for measuring fluids as fixed by law in Germany . . . 127

CHAPTER V.

PREPARATION OF ALLOYS IN GENERAL.

General method of preparing alloys; Utensils used for melting; Crucibles and their management 128

Melting in a reverberatory furnace; Necessity of preserving a deoxidizing flame within the furnace; Loss of metal in melting 129

Precautionary measures in preparing alloys in a crucible; Bodies used for covering the surface of the metals 130

Crucibles for the preparation of alloys from noble or costly metals; Alloying two metals with greatly varying densities 131

Effect of stirring the mixture with sticks of dry, soft wood; Change in the nature of alloys by repeated remelting 132

Method of alloying larger quantities of one metal with smaller quantities of another 133

Causes of the advance in the alloy industry; Metals chiefly used in the manufacture of alloys 134

Methods of making experiments in the preparation of new alloys; Combinations of metals with non-metallic elements. 135

CHAPTER VI.

COPPER ALLOYS.

Difficulty in the employment of copper for various purposes; Influence of foreign bodies upon the properties of copper and its alloys; Effect of a content of lead 137

Effect of various metals upon copper; Influence of an admixture of cuprous oxide; Effect of sulphur 138

Effect of silicon and phosphorus; Hampe's researches regarding the behavior of copper towards admixtures 139

PAGE

Sources of commercial copper; The most important copper alloys; Copper-gold alloys 140

Copper-silver alloys; Alloys of copper with the base metals; Antiquity of bronze 141

Ancient method of preparing brass; Copper-zinc alloys; Earliest account of the alloy of copper and zinc; Influence of zinc upon copper . . . 142

Constitution of copper-zinc alloys; Properties of copper-zinc alloys; Brass, its properties, manufacture, and uses 143

Introduction of the manufacture of brass in Germany, and in England; Composition of commercial varieties of brass; Summary of researches regarding the behavior of alloys of copper and zinc 144

Physical properties of alloys of copper and zinc; Crystalline structure of brass; S. Kalischer's researches regarding metals becoming crystalline . . 145

Examination of different varieties of sheet-brass; Sheets of tombac and bronze-sheets 146

Preparation of a very ductile brass; Strength of brass; Change in the molecular structure of brass; Melting-point of brass 147

Use of old copper in the manufacture of brass; Effect of foreign metals upon brass; Use of brass in the arts 148

Tables of the properties of copper-zinc alloys; Sheet brass for the manufacture of sheet and wire; S. Sperry's investigations regarding the influence of antimony upon the cold-shortness of brass 149

Brands of zinc suitable for the manufacture of brass; Proportions of copper to zinc for sheet-brass which is to resist the action of acid and alkaline fluids; Brass for cartridge shells; Best evidence of the quality of a brand of copper 150

Table showing the composition of different varieties of brass for sheet and wire; Japanese brass (Schin-chiu); Cast brass 151

Analysis of different kinds of cast brass; Ordinary cast brass (*potin jaune*, *potin gris*), sterling metal 152

Fine cast-brass; Tough brass for tubes 153

Hamilton's metal, mosaic gold, chrysorin; French cast-brass for fine castings 154

Bristol brass (Prince's metal); Ronia metal; D'Arcet's gilding metals; Malleable brass; Early patents for malleable brass 155

Varieties of malleable brass; Muntz metal; Yellow metal 156

Macht's yellow metal; Bobierre's metal; Aich's metal 157

Sterro-metal; Sterro-metal from Rosthorn's factory in Lower Austria; English sterro-metal (Gedge's alloy for ship-sheathing) 158

Results of tests of sterro-metal; Delta metal 159

Table of analyses of Delta metal 160

Durano metal; Tobin bronze; Analyses of Tobin bronze 161

Deoxidized bronze 162

Manufacture of brass; Early preparation of brass; Manufacture of brass according to the old method with the use of zinc ores 163

Manufacture of brass by the direct fusion of the metals; Results of experi-

PAGE

ments in fusing the metals directly in special furnaces; Construction of furnaces for crucibles, described and illustrated 165
Furnace adapted for the use of coke 166
Size of Crucibles; Another construction of a brass furnace 167
Furnace for heating the moulds for plate-brass 168
Modifications in the arrangement of furnaces for the use of coal; Piat's revolving crucible furnace, described and illustrated 169
Construction of furnace in which the fusion of the brass is effected directly upon the hearth 170
Manner in which fusion is effected. 171
Casting brass. 172
Casting of ingots; Moulds for casting ingots 173
Importance of the temperature of the fused brass; Casting of plate-brass . 174
Use of iron moulds; Loam moulds; Granite moulds, and their preparation . 175
Subsequent treatment of plate-brass 176
Furnace for heating sheets; Reverberatory furnace for wood firing, described and illustrated 177
Cleansing or pickling of brass; Operation of pickling or dipping; Pickling fluid 179
Organic substances used as additions to the pickle; Mode of imparting a dull lustreless surface to the articles 180
Subsequent treatment of the pickled articles; Tombac; Alloys to which the term tombac is applied; Origin of the word tombac; Properties of pure tombac 181
Table giving the composition of various kinds of tombac; Berlin alloys for lamps and chandeliers; Lyons gold; Color of tombac. 182
Composition of alloys for candlesticks, inkstands, etc.; Mannheim gold or similor; Chrysochalk (gold copper); Chrysorin. 183
Pinchbeck; French orëide; Special formula for the preparation of orëide . 184
Talmi or talmi-gold; Table giving the composition of a few alloys used in the manufacture of articles of talmi gold 185
Tissier's gold; Tournay's metal; Platina; Manilla gold; Dutch leaf or Dutch gold 186
Preparation of Dutch leaf 187
Bronze powders, and their preparation 188
Table giving the compositions of the alloys for some colors of bronze powders; Brocade 189
White brass 190
Birmingham platinum or platinum-lead; Other alloys for white buttons; Sorel's alloy 191
Bath metal; Guettier's button metal; Ordinary English white metal; Fontainemoreau's bronzes 192
Table exhibiting the properties of the alloys of copper and zinc as described by the best authorities 193
Note on the table by Prof. Robert H. Thurston 198

PAGE

CHAPTER VII.

COPPER-TIN ALLOYS.

Bronze in general; Use of bronze among the early civilized people, Origin of the term bronze; Definition of the term bronze 201
Constitution of bronze; Ductility of bronze; Influence of admixtures of foreign bodies upon the properties of bronze; Cause of the difficulties found by many manufacturers 202
Effect of zinc, and of lead upon the properties of bronze 203
Effects of iron, nickel, and other metals; Conditions by which the physical properties of bronze may be materially affected 204
Variations in the color of bronze according to the content of tin; Ductility and hardness of bronzes 205
Deductions from the results of modern researches regarding the strength and hardness of bronzes; Molecular change in alloys rich in copper by forging; Results of quickly cooling off red-hot bronze in cold water. . . . 206
How to secure the greatest strength of bronzes; Table exhibiting the density of various copper-tin alloys 207
Table of melting points of bronzes. 208
Chemical behavior of bronzes towards the oxygen of the atmosphere; Effect of the oxygen; Properties shown by the melted bronze; Preventative against the absorption of oxygen 209
Phosphorus as a deoxidizing agent; Influence of the construction of the melting furnaces upon the loss of metal and the qualities of the castings . . 210
Tendency of bronzes towards liquation, described and illustrated . . . 211
Behavior of the solidified alloys towards the atmosphere; Melting and casting of bronze; Casting small articles 212
Preparation of large quantities of bronze 213
Arrangement of a reverberatory furnace especially adapted for melting not too large a quantity of bronze 214
Construction of a furnace especially adapted for melting a large quantity of bronze 215
The different kinds of bronze; Bronzes of prehistoric times 216
Composition of the older bronzes 218
Composition of some ancient bronzes; Ordnance or gun-metal; Historical notice of the use of bronze for casting cannon 219
Properties demanded from a good gun-metal; How to obtain these properties 220
Additions to actual bronze; Content of tin in bronze for ordnance; Outline of the operations of melting and casting gun-metal 221
Double furnace in use in the gun foundry at Spandau 222
Shaft furnace after the principle of Herbetz's steam injector . . . 223
Use of old cannon in casting ordnance; Influence of the casting temperature upon the physical properties of ordnance-bronze 224
Cooling ordnance-bronze; Moulds used in casting; Steel-bronze . . . 225
Table showing the composition of ordnance bronze of various times and different countries; Bell-metal; Ancient use of bells and cymbals; Introduction of actual church bells 226

PAGE
Weights of some large bells; Principal requisites of good bell-metal . . 227
Properties of bell-metal; Important features on which the tone of a bell materially depends; Melting and casting of bell-metal 228
Reason for bells acquiring a disagreeable tone by repeated remelting; Table showing the composition of some bell-metals 229
Alloys for small clock bells, table bells, sleigh bells, etc.; Chinese tam-tams or gongs 230
Algiers metal (metal d'Alger); Silver bell metal; Bronzes for various purposes 231
Designation of various kinds of bronzes; Medal and coin bronze . . . 232
Composition of the baser coin of several countries; Coin-bronze of the Greeks and Romans; Color of medals; Manufacture of medals 233
Ormolu (or moulu); Actual ormolu; Bronze for small castings; Gold bronze. 234
Bronze to be gilded; Bronze for ship-sheathing 235
Machine bronze 236
Variations in the composition of machine bronze 237
Table showing the composition of machine bronze; Table showing the composition of approved alloys for bearings 238
Table showing the mixtures employed by a large engineering firm using scrap and new metal; Bronze for articles exposed to shocks and very great friction; Bronze for valve balls and other constituent parts to which other parts are to be soldered 239
Bronze resisting the action of the air; Beautiful bronze to be used as a substitute for brass; Deterioration in the quality of bronze by remelting; Remedy for such deterioration 240
Defective bronze castings; Causes of the formation of blisters and pores; Destruction of the oxides present and which may be formed 241
Speculum metal; Properties of good speculum metal; Specula made by Mudge; Composition of the actual speculum metal; Best proportions for speculum metal according to David Ross 242
Table showing the composition of some alloys used for speculum metal; Composition of the mirror of the Ross telescope; Alloy for the manufacture of concave mirrors 243
Telescope Mirror of Birr Castle, Ireland; Mirror in the Polytechnicum, Brunswick, Germany; Roman metal mirror; Old Egyptian metal mirror; Chinese metal mirrors; Phosphor-bronze; Reducing action of phosphorus. 244
Discovery of phosphor-bronze 245
Methods of making phosphor-bronze; Preparation of phosphor-copper, and of phosphor-tin. 246
Preparation of phosphor-bronze wire; Properties of correctly prepared phosphor-bronze; Results of physical tests of phosphor-bronze 247
Applications of phosphor-bronze; Variations in the content of phosphorus in bronze 248
Varieties of phosphor-bronze which are considered to answer all requirements; Analyses of different kinds of phosphor-bronze 249

PAGE
Höper's phosphor-bronze; Phosphor-lead bronzes; Phosphor-aluminium bronze 250
Silicon bronze; Weiller's alloy; Action of silicon upon copper; Properties of silicon bronze; Conductivity and strength of silicon-bronze telegraph and and telephone wires 251
Power of silicon-bronze wires of resisting snow; Composition of silicon-bronze telegraph and telephone wires 252
Composition of silicon-bronze; Bronze for telephone lines; Results of E. Van der Ven's researches. 253
Manganese bronze. 254
Preparation of cupro-manganese 255
Composition of two varieties of cupro-manganese; Preparation of manganese-bronze 256
Quantity of cupro-manganese to be added to bronze; Addition of aluminium. 257
Properties of manganese-bronze; Art bronzes 258
Bronze for casting statues 259
Color of statue-bronze; Patina, and its formation 260
Causes of defects in statue-bronze 261
Table of a series of alloys of different colors suitable for statue-bronze; Statue-bronze according to d'Arcet 262
Table showing the composition of a few celebrated statues; Chinese bronzes; Analyses of different specimens of Chinese bronze 263
Imitation Chinese bronzes 264
Japanese bronzes; Old Peruvian bronze; Turkish bronze basin; Antique bronze weapon 265
Melting and casting art-bronze; Furnace used in the Royal Foundry in Munich 266
Moulds for large castings; Table of different alloys of copper and tin, giving some of their mechanical and physical properties 267
Note on the table 274

CHAPTER VIII.

ALLOYS OF COPPER WITH OTHER METALS.

Copper-arsenic alloys; Copper-lead alloys 277
Copper-iron alloys 278
Copper-steel; Henry Schneider's patents for the manufacture of alloys of iron and copper, and steel and copper 279
Alloys of copper and much zinc; Table giving the composition of alloys for cheaper bearing metals 280
Dunlevie and Jones' bearing metal; Alloys which can be filed; Manganese-brass; Copper-tungsten alloys; Copper-cobalt alloys 281
Cobalt-bronze; Copper-magnesium alloys; Copper-antimony alloys . . 282
Mira metal 283

PAGE

CHAPTER IX.

TIN-ALLOYS.

Tin-lead alloys; Densities of tin-lead alloys 284
Tin-lead alloys for the manufacture of domestic utensils; Fahlun brilliants; Table showing the melting-points of tin-lead alloys 285
Table of alloys for baths used in tempering and heating steel articles . . 286
Britannia metal; Regulations of the Pewterer's Company of England; Properties of Britannia metal; Influence of other metals on Britannia metal . 287
Table showing the composition of several varieties of Britannia metal . . 288
Dr. Carl Karmarsch's investigations of Britannia metal; Preparation of Britannia metal 289
Shaping and casting Britannia metal; Preparation of the moulds for casting. 290
Polishing Britannia metal articles; Biddery metal; Composition of genuine India Biddery metal 292
Ashberry metal; Minofor metal; English metal 293
White metals—Bearing metals; Impracticability of combining many metals into one and the same alloy; Principal use of the so-called white metals . 294
Advantages of white metal bearings; Constitution of white metal bearings; Metallographic examination of congealed white metal 295
Variation in the proportions of the constituents of white metal; White metal bearings of the Berlin Railroad. 296
Bearing metal used by the Austrian Northwest Railroad; Table showing the compositions of the more frequently used compounds for bearings . . 297
Babbitt's anti friction metal 298
German Admiralty specifications for Babbitt metal 299
Kingston's metal; Anti-friction alloys for hydraulic machinery; Fenton's alloy for axle boxes for locomotives. and cars; Dewrance's patent bearing for locomotives; Alloy for anti-friction brasses; Alloy for metal stopcocks which deposit no verdigris; English white metal; Composition of white metal for machines; Hoyle's patent alloy for pivot bearings . . . 300
Alloys used for white metal bearings in the factory of H. Roose of Breslau; Results of C. B. Dudley's investigations of bearing metals. . . . 301
Ex. B. metal of the Pennsylvania Railroad Company 302
Tables of anti-friction metals 303

CHAPTER X.

NICKEL ALLOYS.

Early knowledge of nickel alloys; Meaning of the Chinese name packfong or packtong; Analysis of packfong; Suhl white copper; Prize for the invention of an alloy as a substitute for silver offered in Prussia, in 1823 . . 306
Historical notice of German silver; Various names under which German silver has been known; Nickel-copper alloys 307
Composition of modern small coins of various countries; Berthier's alloy; Copper-sheet with 1 to 3 per cent. nickel; Alloy used in watch factories; Experiments of Künzel and Montefiore Levi 308

PAGE
Nickel-copper-zinc alloys; Properties of German silver; Sources of nickel . 309
Reduction of nickel ores; Relationship between nickel and cobalt, and nickel and iron; Addition of iron to German silver 310
Effect of an addition of silver to German silver; Summary of the properties of nickel alloys 311
Difficulties in the mechanical manipulation of German silver; Use of nickel-alloys in thermo-electric piles; German silver or argentan. . . . 312
Composition of alloys used by various factories; Table of analyses of different kinds of German silver 313
Effect of additions of various kinds of metal to German silver . . . 314
Substitutes for German silver; Nickel-bronze; Bismuth-bronze . . . 315
Manganese German silver; Aphtit; Arguzoid; Ferro-German silver; Silver-like alloy; Platinoid 316
Manganin; Dienett's German silver 317
Pirsch's patented German silver; Alfénide, argiroide, and allied alloys; Toucas's alloy 318
Alloy according to Trabuk; Table of a number of nickel-alloys arranged according to their composition 319
Copper, zinc, and nickel 320
Copper, zinc, nickel, lead; Copper, zinc, nickel, iron 321
Copper, tin, nickel, with or without zinc; Copper, nickel, silver (Ruolz alloys) 322
Other alloys 323
Sperry's analyses of nickel alloys; Manufacture of German silver on a large scale, Importance of the purity of the metals used 324
Different methods of manufacturing German silver; German process . . 325
Casting the alloy; Moulds used in casting plates 326
Principal difficulty in casting plates of German silver; English process; Mode of melting the metals together 327
Manner of ascertaining how the alloy will act in casting; Casting of the plates. 328
Uses of German silver; Manufacture of German silver sheet; Heating furnace for direct firing 329
Muffle furnaces 331
Nickel-zinc alloy; Nickel-tin alloy 332
Nickel-aluminium alloy; Silver-bronze; Solbisky's nickel-aluminium alloys; Roseïn; Martino's hard alloys for drilling and cutting tools; Nickel-steel; M. Henry Schneider's patents; Specifications of the first patent . . 334
Marbeaus' nickel-spiegel; Preparation of ferro-nickel and nickel-steel alloys for technical purposes; Preparation on a large scale of 5 per cent. nickel-iron 335
Preparation of nickel-steel at Homestead, Penna.; Riley on nickel-steel . 336
Tests of nickel-steel made for the U. S. Navy Department; Conductivity of nickel-steel 337

PAGE

CHAPTER XI.

ALUMINIUM ALLOYS.

Alloying power of alluminium; Practical production of aluminium alloys . 338
Properties of aluminium alloys: Aluminium-iron alloys 339
Aluminium-steel; Mode of applying the aluminium; J. W. Langley on the practice in the United States 340
Aluminium-copper alloys; Aluminium-bronze; Properties of aluminium-bronze 341
Melting-point of aluminium-bronze; Importance of the purity of the metals used in the preparation of aluminium-bronze 342
Directions of the "Magnesium and Aluminium Fabrik" of Hemelingen for making aluminium-bronzes 343
Dilution of a high per cent. bronze to a lower one 344
Casting of aluminium-bronze 345
Thomas D. West on casting aluminium-bronze, and other strong metals . 346
Forging of aluminium-bronze; Examples of rolling aluminium-bronze . . 347
Table of results obtained at the South Boston Iron Works with pieces of the Cowles Company alloys; Tests made at the Washington Navy Yard . . 350
Mode of preparing aluminium-copper alloys according to Thurston; Aluminium-brass; Action of aluminium upon brass 351
Uses of aluminium-brass 352
Table of results of a series of tests of aluminium-brass; Richards bronze . 353
Aluminium-nickel-copper alloys; Alloys manufactured by the "Webster Crown Metal Company," England 354
Lechesne; Alloys specified by the patent 356
Alloys recommended by G. F. Andrews; Sun-bronze; Metalline; Aluminium alloy for dentists' fillings; Aluminium alloy for type-metal; Aluminium-nickel bronze 357
Partinium; Aluminium-bronze alloy; Aluminium-chromium alloy; Aluminium-magnesium alloy called magnalium 358
Aluminium-magnesium alloy for reflectors; Alloy of aluminium and tin; Brazing aluminium-bronze 359
Soldering aluminium-bronze; Hard solder for 10 per cent. aluminium-bronze; Middling hard solder; Soft solder; Schlosser's directions for preparing solder for aluminium-bronze 360
Soldering aluminium; Mourey's aluminium solders 361
Bourbouze's aluminium solder; Frischmuth's aluminium solders; M. H. Lancon's method of preparing aluminium solder 362
Solder for wire and thin articles; Solder for large pieces of aluminium and aluminium sheets; Platinum-aluminium solder; Gold-aluminium solder; O. M. Thowless' solder for aluminium; C. Sauer's solder . . . 363
Chloride of silver as a solder for aluminium; Richards's solder . . . 364

PAGE

CHAPTER XII.

LEAD ALLOYS.

Effect of the addition of other metals to lead; Affinity of zinc and iron for lead 366
Type-metal; Properties of an alloy which is to serve for type-metal . . 367
Table of some alloys suitable for casting type; French and English type-metals 368
Erhart's type-metal; Manufacture of type; Alloy for plates for engraving music 369
Alloy for keys of flutes and similar parts of instruments; Shot-metal; Mixture of metals used; Precautions to be observed in preparing the alloy; Preparation of the alloy 370
Proportions of arsenic to lead used in England and in France; Effect of the arsenic 371
Casting of shot; Invention of Watts; Shot-towers and shot-wells . . . 372
Water for the reception of the shot; Formation of shot by centrifugal force; Invention of David Smith for the manufacture of drop-shot . . . 373
Sorting the shot 375
Preparation of large shot; Alloys of lead and iron 376
Alloys of lead and other metals 377

CHAPTER XIII.

CADMIUM ALLOYS.

Properties of cadmium alloys; General composition of cadmium alloys; Lipowitz's alloy 378
Cadmium alloys of various melting points 379
Very fusible alloy; Wood's alloy or metal; Cliché metal; Table of melting points of fusible alloys; Stability of cadmium alloys 381

CHAPTER XIV.

BISMUTH ALLOYS.

Behavior of bismuth towards other metals; Alloys of bismuth and copper; Alloys of bismuth and zinc; Alloys of bismuth and tin 382
Alloys of bismuth and lead; Alloys of bismuth and iron; Alloys of bismuth with antimony; Cliché metal 383
Alloys for filling out defective places in metallic castings; Alloys of bismuth, tin, and lead; Newton's metal; Rose's alloys; Safety-plates for steam boilers; Composition of some alloys which are said to melt at a certain pressure of steam 384
Onion's flexible alloy; D'Arcet's fusible alloys; Lichtenberg's metal . . 385
Bismuth alloys for delicate castings; Bismuth alloy for cementing glass; Table of fusing points of the fusible combinations of bismuth, lead, and tin. 386
Baths for tempering small steel tools, and their use; Alloys of bismuth and tin 387

PAGE

CHAPTER XV.

IRON ALLOYS (ALLOY STEELS).

Derivation of the substances which combine with iron and alloy with it; Associates of commercial iron; Properties of the purest iron which can be made by melting processes on a large scale 388
Most important constituent of iron; Distinctive mark of the different varieties of iron; Classification of iron; Effect of silicon on iron 389
Effect of manganese on iron; Manganese-steel; Ferro-manganese and its use. 390
Hadfield's manganese steel; Use of manganese steel; Chrome-steel; Modes of uniting iron and chromium 391
Ferro-chrome from Kapfenberg in Styria; Preparation of chrome-steel; Effect of chromium in steel 392
Properties and uses of chrome steel; Tungsten-steel; Ferro-tungsten . . 393
General effect of tungsten in steel; Results of bending tests conducted on bars of tungsten-steel 394
Peculiarity of the fracture of tungsten-steel; Magnetic retentiveness of tungsten-steels with a high content of carbon; Analyses of special tungsten-steels 395
Vanadium-steel; Discovery of the element vanadium; Present importance of vanadium-steel 396
Hélouise's investigations of the effect of vanadium on steel 397
Properties of steel with and without vanadium, according to J. Kent Smith; Results of Prof. Arnold's bending tests on vanadium-steel . . . 398
Remarks of J. Kent Smith on vanadium and its action; Table of comparative effects of chromium and vanadium on static tests 399
Table showing the different ways in which vanadium may act on steel; Preparation of vanadium 400
Classification of vanadium steels; Results obtained by the addition of vanadium 401
Results obtained with vanadium and nickel; Vanadium chrome-steels and the best proportions for them; Effect of chromium 402
Table of results of experiments showing the influence of vanadium on chrome. 403

CHAPTER XVI.

SILVER ALLOYS.

Alloys of silver of real interest; Alloys of silver and aluminium . . . 404
Tiers-argent (one-third silver); Alloys of silver and zinc; Godfrey's alloys. 405
Properties of alloys of silver and zinc; Alloys of silver, copper, and nickel. 406
Argent-Ruolz; Alloys containing silver and nickel, patented by C. D. Abel. 407
Purification of nickel; Treatment of nickel-speiss 408
Preparation of Abel's alloys 409
Alloys of silver, copper, nickel, and zinc 410
Alloys for Swiss fractional coins; Mousset's silver alloys; Alloys of silver and arsenic; Alloys of silver, copper and cadmium 411

PAGE
Alloys of silver with various metals; Alloys of silver and copper . . . 412
Present determination of the fineness of coins; Table showing the composition of the silver coins of various countries 413
Silver-copper alloys employed in England for manufacturing purposes . . 414
Fineness of silver used in the manufacture of silver-ware in different countries; Casting of silver; Blanching 415
Remarkable series of alloys of the Japanese; Shaku-do; Shibu-ichi, with typical analyses 416
Pickling solutions used by the Japanese; The so-called "antimony" of the Japanese art metal-workers 417
Action of the pickling solutions; Production of various Japanese alloys; Moku-me; Niyu-nagashi 418
Alloys resembling silver; Warne's metal; Minargent; White alloy closely resembling silver; Delalot's alloy; Tournu-Leonard's alloy . . . 420
Clark's patent alloy; Pirsch-Baudoin's alloys 421

CHAPTER XVII.

GOLD ALLOYS.

Early use of gold dust as the principal medium of exchange, the instrument of association; Sacred value placed on gold by the Egyptians; Inutility of the majority of gold alloys 422
Mutual affinity of gold and copper; Combinations of gold and silver; Modifications of the color of gold; Gold-alloys of various colors; Behavior of lead towards gold 423
Alloys of arsenic or antimony and gold; Alloys of gold and palladium; Alloy of aluminium and gold; Nuremberg gold; Action of cadmium on an alloy of gold and silver; Preparation of gold alloys 424
Manufacture of gold articles; Casting gold for coinage; Casting ingots for the preparation of gold-plate; Melting the metals constituting the alloys . 425
Furnace used by manufacturers of gold ware 426
Preparation of granulated gold; Production of very tough gold; Remelting scrap gold; Legally fixed standards for gold alloys 427
Conversion of carats and grains into thousandths; Use of gold-alloys; Standard gold 428
Remedy allowed by English law for abrasion or loss by wear: Table showing the fineness of gold coinage of various countries; Gold alloys for the manufacture of jewelry; Legally fixed standards for gold jewelry . . . 429
Table of gold-alloys as legally fixed by various governments; Gold-alloys which can be legally used in various countries; Pforzheim gold-ware; Table showing the proportions of various metals incorporated in the gold-alloys used by jewelers 430
Colored gold; Table showing the composition of the alloys most frequently used, with their specific colors 431
Preparation of alloys of gold by the galvanic process; Coloring finished gold-alloys 432

PAGE

CHAPTER XVIII.

ALLOYS OF PLATINUM AND PLATINUM METALS.

Alloying power of platinum; Properties of platinum-alloys; Composition of platinum occurring in nature; Furnace for melting platinum . . . 433
Preparation of platinum alloys on a small scale; Platinum-iridium alloys . 434
Alloy for laboratory crucibles; Composition of meter rules of the French government; Platinum-palladium alloys 435
Platinum-gold alloys and their uses 436
Platinum-silver alloys; Platine au titre; Platinum-gold-silver alloys; Platinor 437
Platinum-bronze 438
Alloys of platinum with the base metals; Alloys with iron; Properties imparted to steel by an addition of platinum; Alloys of platinum and copper. 439
Golden-yellow alloys of platinum and copper; Composition of alloys used in the manufacture of jewelry 440
Cooper's mirror-metal; Cooper's pen-metal; Palladium alloys; Palladium bearing metal 441
Alloys of palladium and silver; Palladium alloys for bearing metal; Alloys of platinum and iridium; Alloy of iridium with osmium; Alloy for watch manufacturers 442
Phosphor-iridium, and process of preparing it 443

CHAPTER XIX.

ALLOYS OF MERCURY AND OTHER METALS OR AMALGAMS.

Properties of mercury; Amalgams as a means of studying the behavior of the metals towards each other 445
Affinity of metals for mercury; Gold amalgam; Chemical combination of gold with mercury 446
Preparation of an amalgam suitable for fire-gilding; Gold-amalgam containing silver, and its preparation 447
Native gold-amalgam; Silver amalgam; Fire-gilding 448
Amalgamating water 449
Copper amalgam: Peculiar properties of this amalgam 450
Directions for preparing copper-amalgam; Vienna metallic cement . . 451
Dronier's malleable bronze: Tin amalgam; Amalgam for mirrors and looking glasses 452
Amalgam for coating rubbers of electric machines 453
Singer's amalgam for coating rubbers of electric machines; Musiv silver; Amalgam for tinning; Zinc amalgam; Amalgamation of zinc for voltaic cells 454
Spurious gilding of copper; Cadmium amalgam 455
Amalgams for filling teeth; Evans's metallic cement; Amalgams of the "fusible alloys"; Amalgam of Lipowitz's metal 456

PAGE

Production of impressions of objects of natural history; Manufacture of small statuettes; Iron amalgam 457
Bismuth amalgam 458
Amalgam for silvering glass globes; Amalgam of bismuth for anatomical preparations 459
Preparation of metallic pencils; Pholin's silver-like alloy; Sodium amalgam. 460
Rosenfeld's process of preparing sodium amalgam; Potassium amalgam . 461
Nickel amalgam; Platinum amalgam; Mackenzie's amalgam . . . 462

CHAPTER XX.

MISCELLANEOUS ALLOYS.

Mixture especially adapted for serving as a protective cover in remelting alloys; Alloy for spoons; Alloy resembling German silver; Alloy resembling silver; Non-oxidizable alloy; Calin; Alloy for moulds for pressed glass; New method of preparing alloys 463
Alloys of indium and gallium 464
Steel composition; Alloys for drills, chisels, etc.; Alloys of iron with chromium, tungsten, molybdenum, etc. 465
Alloys of copper and iron; Malleable ferro cobalt and ferro-nickel. . . 466
Bronze resisting acid; Zinc-iron; Alloy which expands on cooling. . . 467
Spence's metal; Lutecine or Paris metal; Alloys for small patterns in foundries 468
Alloys for calico-printing rollers; Dépierre's and Spiral's researches on this subject 469
Tables showing the physical properties and chemical composition of calico-printing rollers. 470
Alloys for compensation balances 471
Black bronze; Sideraphite; Violet-colored alloy; Gold-like alloy . . . 472
Pyrophorous alloys for illuminating purposes; Alloy for silvering. . . 473
Robertson alloy for filling teeth; American sleigh bells; Alloy for casting small articles; Marlie's non-oxidizable alloy; Alloy for sign-plates . . 474
Victor metal; Tempered lead 475

CHAPTER XXI.

SOLDER AND SOLDERING.

Solders in general; Definition of soldering; Varieties of solders; Conditions to be observed in soldering 476
Autogenous soldering; Binding the work in soldering; Binding wire; Handling the work in soldering 477
Soft solders; Pure tin as a solder; Composition of soft solder most frequently used; Table of soft solders 478
Solders for plumber's work, for lead and tin pipes, Britannia metal, etc.; Plumbers' sealed solder; Preparation of soft solder 479
Judging the quality of a solder; Bismuth solder; Hard solders; Brass solder 480

PAGE
Preparation of brass solder 481
Table showing the composition of various kinds of brass solder . . . 483
Prechtl's brass solders; Brass solders according to Karmarsch; Improved hard solder for brass; Argentan solder 484
Readily fusible argentan solder; Less fusible argentan solder . . . 485
Solder containing precious metals 486
Ordinary hard silver-solder; Brass silver-solder; Soft silver-solder; Hard silver-solders 487
Solders for special work 488
Silver-solder for cast-iron; Silver-solder for steel; Flux for hard soldering used in Vienna; Gold-solders 489
Table showing the composition of some gold-solders in general use; Solder for enameled work; Refractory solder; More readily fusible solder . . 490
Fine gold solder; Aluminium gold-solder; Treatment of the various solders in soldering; Soldering fluids, etc. 491
Use of dilute mineral acids for pickling the places to be soldered; Soldering fluid and its preparation 492
Soldering fat; Fluxes used in hard soldering; Use of quartz-sand as a flux . 493
Soldering copper and brass; Table giving the compositions and melting-points of solders, and fluxes used 494
Soldering jewelry: Soldering pan 496

CHAPTER XXII.

DETERMINATION OF THE CONSTITUENTS OF METALLIC ALLOYS, OF THE IMPURITIES OF THE TECHNICALLY MOST IMPORTANT METALS, ETC.

Manner of dissolving metals; Characteristics that indicate the presence of various metals in the solution 498
Mode of testing for mercury; Precipitation of metallic sulphides; Apparatus for the preparation of sulphuretted hydrogen 499
Determination of magnesium 500
Determination of nickel and cobalt, and of iron, chromium and manganese . 501
Determination of zinc, alumina, silver, gold, and platinum 502
Determination of antimony and of tin, bismuth, copper, and cadmium; Determination of arsenic, and Marsh's apparatus for that purpose . . . 503
Testing brass 504
Testing Britannia metal; Testing bronze 505
Testing German silver; To test gold-ware 506
Resistance of a few metals and alloys to calcium hydrate 507
To distinguish tin-foil from lead-foil; To test mercury as to its purity; Testing tin as to its purity; Testing soft solders; To detect lead in tin; Testing white metal; Testing nickel 508

PAGE

APPENDIX.

COLORING OF ALLOYS.

Lacquers used; Graham's table of lacquers 510
Mode of obtaining a coating similar to genuine patina upon bronze . . 511
Production of all shades from the pale-red of copper to a dark chestnut-brown 512
Brown upon copper; Red-brown on copper 513
Bronzing copper according to Manduit; Coloring copper blue-black; Cuivre fumé; Black color upon copper; Matt-black on copper; Bronze upon French bronze figures 514
Graham's bronzing liquids 516
Lustrous gray or black coating upon articles of brass or bronze . . . 517
Production of iridescent coatings; Various colors upon small articles of brass; Production of a beautiful gold color 518
Beautiful silver color upon brass 519
Browning liquid for copper; Ebermayer's directions for coloring brass . . 520
Coloring soft solders; Bronzing of copper, bronze-metal and brass . . 521
Production of brown bronze color; Red-brown or copper-brown upon copper; Production of green bronze-color; Coloring zinc 522
Gray, yellow, brown to black colors upon zinc; Bronzing on zinc; Red-brown on zinc; Yellow-brown shades on zinc; Browning gun barrels . . 523
Lustrous black on iron; Durable blue on iron and steel; Brown-black coating with bronze luster on iron 524
To give iron a silvery appearance with high luster; Bronze-like patina on tin; Warm sepia-brown tone upon tin and its alloys; Oxidizing silver . 525

RECOVERY OF WASTE METALS.

Recovery of gold and silver from sweepings and from wash-water in gold-workers' shops; Recovery of gold from coloring baths 526
Recovery of gold from auriferous fluids; Recovery of gold from old cyanide solutions 527
Separating silver 528
Recovery of silver from old cyanide solutions; Recovery of silver by the wet method 529
Utilization of nickel waste 530
Recovery of copper; To separate silver from copper; Recovery of tin from tin-plate waste 531
Recovery of brass from a mixture of iron and brass turnings . . . 532
Index 533

THE METALLIC ALLOYS.

CHAPTER I.

INTRODUCTION.

A CHEMICAL examination of a technically prepared metal shows in most cases the presence of smaller or larger quantities of one or more foreign metals. Thus, in commercial iron are nearly always found: Manganese, copper, and frequently cobalt and nickel; in commercial copper: Iron, lead, silver, gold, nickel, antimony and other metals; in zinc: Iron, arsenic, etc. But the presence of these foreign metals can with certainty be established only by chemical analysis; they cannot be recognized as independent bodies by the eye, nor is it possible to separate them by purely mechanical means.

These facts indicate a quite strong endeavor of the metals to combine with one another; and a combination of two or more metals in such a manner that the separate metals in the combination can no longer be distinguished is called an *alloy*. However, when mercury is one of the metals entering into combination, the result, as a rule, is not termed an alloy, but an *amalgam*.

By alloying a metal with one or more other metals its properties are changed in a remarkable manner; the fusing point may be lowered, the hardness and strength increased, etc. Hence, by properly alloying a metal its properties may be so affected as to render it more suitable for the purpose for which it is to be used; injurious properties may be decreased and desirable ones produced. This is the reason

why gold, silver, copper, lead, tin and other metals are actually more rarely worked in a pure, than in an alloyed, state.

The earliest historical data in reference to the development of the art of preparing, so to say, new metals by melting together several metals are very meager, and though it appears from several passages in sacred, as well as profane, history that no metallic compound was in more general use with the ancients than brass, the mode of its manufacture is left in obscurity by the historiographers of subsequent ages. Pliny says that a flourishing trade in brass was carried on in Rome shortly after the founding of that city, and that Numa, the immediate successor of Romulus, formed all the workers in this alloy into a kind of community.

The Greeks possessed considerable knowledge in the art of mixing metals, and knew how to prepare alloys with special properties which rendered them suitable for particular purposes. They understood, for instance, the preparation of alloys which were especially hard, or well adapted for casting. The oldest alloys we know of always contain copper, which is, no doubt, due to the fact that this metal occurs native in many places, and is also readily reduced from its ores. Next to alloys containing copper, we find those of the noble metals—silver and gold—with a base metal, generally copper.

It is not difficult to explain why the noble metals were alloyed in early times with other metals. On the one hand, these metals were much more expensive than at the present time, and, being subject to considerable wear on account of their softness, it was but natural that some one, recognizing the great similarity between the heavy metals as regards ductility, weight and luster, should have instituted experiments in order to see how these metals would behave towards each other when melted together. Experience then showed that by melting together, for instance, a certain

quantity of silver with copper, the properties of silver, especially its white color, were retained, while the hardness and power of resistance of the alloy were considerably increased.

There can scarcely be any doubt that the alloys of copper with tin, generally called bronze, were the earliest mixtures of metals, because zinc, in a metallic state, has only been known at a later period, while tin was known in the earliest historic times. Next in historical order follow the alloys of noble metals with each other, and with copper. Mercury, which occurs free in nature, was also known to the ancients, and its metallic properties recognized by them, as is evident from the name—hydrargyrus (water-silver)—by which it was designated. It is certain that compounds of it, which, at the present time, are known as amalgams, were used by the Greeks and Arabians. From what has been said, it would seem likely that the ancients understood the art of fire-gilding metallic articles with the assistance of gold amalgam; and, in fact, some old statues which had evidently been gilded have been found—the best example of it being the statue of the Roman emperor Marcus Aurelius, which now stands in front of the capitol at Rome.

Up to the commencement of the reign of Charlemagne, when the development of the technical arts commenced in Europe, the only mixtures of metals were the alloys of copper, tin, zinc, silver and gold, and some amalgams. To prepare other alloys a greater knowledge of chemistry was required than that possessed by the early races of mankind. The development of chemistry was principally due to the Arabs, and especially to those settled in Spain —the Moors—who were well learned in the chemical sciences and in all branches of natural history, and probably well aware of many mixtures of metals still used at the present time. At later periods it was alchemy, the vague hallucination of making gold from lead and other base metals, which prompted men to undertake investigations

fruitful of chemical deductions and promotive of a knowledge of the metals. Many an alchemist found in his crucible alloys, which he threw away unsatisfied, because they did not possess the properties of the desired gold, but which at the present time are profitably used. It may be said without exaggeration that modern chemistry would not have reached such a degree of excellence if it were not for the great abundance of facts collected by the alchemist to be marshaled into a science thereafter.

From what has been said, it will be seen that at the time when chemistry as a science did not exist, considerable was known in regard to alloys, and we find that in the middle ages a large number of mixtures of metals were used in the various arts and industries. The preparation of the alloys, however, was always affected in a very crude manner, but little being known about the definite proportions in which the metals had to be melted together in order to obtain alloys of determined properties. The only exception to this were the alloys obtained by the direct melting together of the pure metals, for instance, those prepared from the noble metals and copper. As is well known, everything relating to coinage had reached a considerable degree of excellence in the middle ages, and the fineness of a mixture of metals which was to be used for coinage could be determined with considerable accuracy.

When chemistry entered the ranks of the sciences, the art of preparing alloys became a branch of it. The chemists gradually investigated all the bodies occurring in nature, and showed how from minerals a series of metals could be gained, which were not known up to that time. These metals were examined as to their intrinsic properties and their behavior towards each other, and it was observed that a large number of their mixtures possessed properties which rendered them suitable for technical purposes.

Although it may be said that our knowledge of chemistry has advanced so far that at present all metals of importance

in the arts and industries are known, our knowledge of the metals themselves cannot be considered complete, as in recent times several new metals have been discovered which may become of a certain importance in the preparation of alloys. The fact that these metals are at present quite rare and that their preparation is connected with great expense, is not adverse to this conjecture, since many examples could be cited of bodies, for instance, aluminium, which not so many years ago were considered expensive rarities, but are now produced on a large scale, and used for industrial purposes.

From what has been said, the science of metallic alloys must be considered as a branch of knowledge which, though brought to a high degree of perfection, is by no means complete. It rather opens a wide field for the activity of the chemist, and the invention of a new useful alloy belongs to the most important and valuable discoveries, since nearly every alloy possesses certain specific properties which make its application to many branches of industry especially valuable.

From the explanation previously given it is evident that an alloy cannot be a mere mechanical mixture of several metals, and hence there remains only the possibility of its being either a chemical combination or simply a solution of one metal in another, similar to a solution of common salt in water, of ether in alcohol, of sulphur in carbon disulphide, etc.

A chemical combination would seem to be indicated by the development of heat which takes place when certain metals in a fused state are mixed one with the other; further by the frequently considerable variations in the physical properties of the alloys from those of their constituents (color, specific gravity, fusing point, power of conducting electricity, etc.); by the crystallizing power of many alloys; and finally by the fact that from alloys in a liquid state, when heated but little above the fusing point,

solid crystals of varying composition are not unfrequently separated—Pattinson's desilverizing process of argentiferous lead—whereby from the fused lead crystals of an alloy poorer in silver may be separated and skimmed off, while the lead richer in silver remains behind in a liquid state. However, it must be remembered that very similar processes also take place in numerous cases with solutions, but with the difference, that solutions are, as a rule, liquid at the ordinary temperature, while alloys, almost without exception, acquire a fluid form only at a higher temperature. On mixing sulphuric acid with water, development of heat takes place in all cases and with all proportions of weight, without a new hydrate of sulphuric acid being formed every time; the same phenomenon may be observed when absolute alcohol is mixed with water, and in many other mixtures. However, the physical properties of ordinary solutions very frequently vary from those of their constituents in the same manner as we are accustomed to see in many alloys. If common salt is dissolved in water, the specific gravity of the solution is greater, hence the volume smaller, than it should be according to calculation if a mere mechanical mixture had taken place; the same phenomenon being exhibited also with solutions of numerous other salts and liquids, of water with alcohol, with sulphuric acid and many other bodies. On the other hand, it frequently occurs that the specific gravity is less and the volume greater than according to the average calculation, this being the case with most solutions of ammonia in water. While the melting point of sodium chloride (common salt) lies at about 1112° F. and that of pure frozen water at 32° F. solutions of the salt in water solidify only at temperatures below 32° F. Numerous other solutions show a similar behavior. However, on slowly cooling a common salt solution to below the freezing point, a solidified solution poorer in salt is first separated, while one richer in salt remains temporarily behind in a fluid

state; by continuing the cooling a second separation into a solidifying solution poorer in salt and one richer in salt remaining behind takes place, and so on. This process is used in northern climates for the concentration of the content of the salt in sea water, as well as in working poor brine, and, in fact, closely resembles the above-mentioned Pattinson process of enriching the content of silver in lead. In this respect numerous other analogies might be shown; for instance, on solidifying an aqueous solution of alcohol, one poorer in alcohol is first separated, and so on.

From these comparisons it will be seen that the above-mentioned properties of alloys are by no means a certain proof for their being actual chemical combinations; nor is their power of crystallizing always a sure sign of chemical union. Although the crystals of alloys occasionally belong to another system of crystallization than the crystals of each respective separate metal, their composition does not always correspond to definite atomic proportions, but frequently moves within very wide limits. Thus gold-tin alloys, with a content of 27 to 43 per cent. of gold, crystallize in the dimetric system without a composition according to atomic proportions being necessary therefor. Antimony-zinc alloys in all proportions of from 30 to 70 per cent of zinc, yield beautifully formed rhombic prisms or octahedrons, etc. As is well known, when solutions, fluid at the ordinary temperature, are subjected to freezing, crystals are formed in them, the composition of which is not always dependent upon chemical atomic proportions, but chiefly upon the solidifying temperature, and hence, are nothing but solidified solutions, as, for instance, the common salt solutions in water, previously mentioned.

The property of many metals, already referred to, to alloy with each other in all desired proportions by weight, independent of their chemical atomic weight shows that at least not every alloy represents a pure chemical combination, but that in most cases a solution of one metal in

another, or of one or more chemical combinations, in the excess of one of the constituent metals must be present. However, it cannot be doubted that as in the case of other solutions, actual chemical combinations of separate constituents of the alloys are under certain influences formed, and under altered conditions again disintegrated without the nature of the alloy itself being dependent on the presence or non-presence of such intimate combinations. Thus, for instance, when copper absorbs oxygen, a chemical combination of both bodies—cuprous oxide, Cu_2O — is formed, which is soluble in the excess of the melted copper and this solution must therefore be considered an alloy of copper with cuprous oxide. When iron absorbs sulphur, ferrous sulphide, FeS, is formed and dissolves in the excess of iron. Such cases occur frequently.

The manner of the above-mentioned combinations will depend partly upon the general chemical behavior of the metals to one another, partly upon the proportions by weight in which the metals are present in the alloy, partly upon the aggregate state and, with alloys in a fixed state, upon the temperature to which they have been heated above these melting points. It is very probable that by strong overheating above the melting point, a different grouping of the atoms may in some cases take place than by less heating, and that during the transposition into the solid state, a change in the mutual relations may again take place. The time of reciprocal action, the manner of mixing, etc., may also be of influence thereby. This explains partly the variations which are frequently observed in apparently the same alloys when prepared in a different manner, heated to different temperatures, or kept in a fluid state for a time of varying duration.

Alloys in a fixed state are therefore essentially solutions of two or more metals one in another. Solutions of metalloids in metals also belong to the alloys so long as the metallic characteristics—metallic luster, opaqueness, con-

ductivity for heat and electricity—have been preserved. In fact the boundary between metals and non-metals—metalloids—cannot always be sharply drawn. Many bodies which formerly were universally enumerated among the metals, and which even now are in industrial life called metals, have by reason of their chemical properties been transferred by the chemists to the non-metals, as for instance, antimony and bismuth. The conception of the term alloy is therefore quite a comprehensive one. Lead and tin combine with antimony to alloys employed for many purposes; arsenious lead as used for the production of shot is simply an alloy of the metal lead with the non-metal arsenic. Even iron can from its behavior be only considered as an alloy with carbon or silicon.

While some non-metallic bodies dissolve one in another with perfect ease and in all proportions by weight—water and alcohol, calcium chloride and water, ether and alcohol and many others—others possess this property only to a limited extent—water and ether, water and common salt—and still others scarcely dissolve one in another at all, but when mechanically mixed separate again according to their specific gravity—water and oil. A similar variation in the power of alloying is also shown by the metals. Some of them alloy readily and in every proportion by weight; others only to a limited extent, and some not at all. However, it depends also on the temperature, the solubility of the metals one in another being not seldom increased by raising the temperature above the fusing point, though the reverse happens also.

A definite general law for the alloying power of metals towards each other cannot be laid down. Generally speaking, it may be said that alloys of a similar chemical behavior alloy, as a rule, with greater ease than when great differences exist in this respect.

Alloys are nearly always formed in a liquid state at a temperature more or less above the ordinary one. At the

latter they are solid like the great majority of metals, and it is this property which renders them suitable to be used for numerous useful articles. Many alloys of mercury—the only metal with the exception of gallium which is liquid at the ordinary temperature—form, however, an exception. They, like the metal itself, solidify only at temperatures below 0°, but an application of them to the manufacture of useful articles has thus far not been found.

For the production of alloys all the constituents may be liquid or only separate ones, the others in a solid state being dissolved in them. Just as a lump of common salt dissolves in water of the ordinary temperature—a temperature many hundred degrees below the fusing temperature of the salt—copper dissolves in melted tin without the latter being heated to the fusing point of the former. Silver in the same manner dissolves in lead, carbon in iron, and there are numerous similar cases. Combination, however, takes place more rapidly, when both bodies are in a fused state.

It has previously been mentioned that in combining the constituents to alloys, heat is sometimes developed, the temperature rising suddenly, while in other cases heat is fixed, the temperature being lowered. Development of heat, for instance takes place in alloying gold with aluminium, lead with bismuth; while heat is consumed in alloying lead with tin, and, according to Phipson, to a very considerable extent, in alloying lead 207 parts, tin 118, bismuth 284 and mercury 1.6. The development of heat observed in alloying two metals is to be sure, not always in consequence of this process, but is sometimes caused by incidental processes. Thus, for instance, almost all copper contains quite a considerable quantity of cuprous oxide. Now, when such copper is alloyed with zinc or aluminium, the cuprous oxide is decomposed while a corresponding quantity of zinc or aluminium is consumed, and as the generation of heat is thereby greater than the consumption of

heat for the decomposition of the cuprous oxide, heat must be liberated.

There are, however, exceptions to the rule according to which alloys are formed in the liquid state. If, for instance, copper is exposed to the action of zinc vapors, the two metals form an alloy, without fusion being required. Even two solid bodies may sometimes alloy, without fusion, by intimate contact at a higher temperature, and not only on the surface but, if the action is sufficiently prolonged, also to greater depths from the surface in consequence of a penetration—a molecular migration—whereby the body entering from the outside is passed from molecule to molecule. The best known process of this kind is the absorption of carbon by iron poor in carbon when heated in charcoal or other carbonaceous substances (production of steel by cementation). A similar case is the absorption of iron by nickel when both metals are heated in contact with with each other. However, Spring has shown by experiments that mixing the bodies in the form of a fine powder and exposing the mixture to a very strong pressure is sometimes sufficient to eombine them to an actual alloy.

CHAPTER II.

PHYSICAL AND CHEMICAL RELATIONS OF THE METALS.

Before entering upon a description of the manufacture of alloys, it will be necessary to give a general review of the physical and chemical properties of the metals; such knowledge of the elements to be alloyed being required in order to proceed according to a determined plan, as otherwise satisfactory results could only be obtained by a happy accident.

Most of our readers, no doubt, possess this information; but memory might fail some of them, and some essential, though elementary, details may escape others. Nevertheless, a book like this should be complete, and include all the rudiments absolutely necessary for the understanding of the subject, without the trouble of searching for the information in other books.

The elements are generally divided into two great groups, viz. metals and non-metals, or metalloids. This classification of the elements dates from a time when a number of physical properties were ascribed to the metals, which were thought to be peculiar to them and which were considered suitable for their distinction from the non-metals. Such characteristic and peculiar properties of the metals were, for example, their lustre—whence the term "metallic lustre"—their conductivity for heat and electricity, a high specific gravity—exceeding six—opaqueness to light, and others.

It is now known that none of these physical characteristics belong exclusively to the metals. Iodine, tellurium, and graphite possess metallic lustre. Tellurium conducts

heat, and graphite, as well as selenium (in a less degree) conducts electricity. On the other hand, metals are known, for instance, potassium snd sodium, of which the specific gravity is not only less than six, but which are even lighter than water.

The exact meaning of the words *metals and non-metals* cannot be sharply defined, as it is impossible to say what properties are exclusively peculiar to the former and what to the latter, just as it is impossible to exactly classify any series of natural substances.

For our purposes certain distinctive characteristics of the metals to be considered in connection with the manufacture of alloys can, however, be given without difficulty.

a. Physical Relations of the Metals.

By the term metal is, as a rule, understood in ordinary life, a body, which, besides high specific gravity, a characteristic color, and especially a characteristic lustre, shows other definite properties. It is, for instance, frequently supposed that all metals possess a high degree of ductility, that they are opaque, fuse only at a high temperature, and on exposure to the air undergo a slow alteration or, as is the case with the so-called noble metals, retain their color under all circumstances.

The properties above named undoubtedly belong to the metals ordinarily understood by that term and chiefly used in the industries. In considering, however, the bodies termed metals from the standpoint of the chemist, we find that many of them, which must unquestionably be included in that group, show properties differing very much from those enumerated above. If we first turn to the ordinary well-known metals, we find them distinguished by a characteristic lustre, termed metallic lustre, this property being even possessed in a very high degree by such metals as appear entirely lusterless in consequence of their chemical properties (*i. e.*, in contact with the air). If a lump of lead

be cut across with a knife, the fresh surface shows a beautiful luster, but will very speedily tarnish by the lead undergoing a rapid alteration on exposure to the air.

Besides high specific gravity and metallic luster, other general properties are ordinarily ascribed to metals, prominent among which is malleability. It is, however, well known to every one handling metals that they manifest great variations in capacity for extension under the hammer or between rollers. Some of them, like gold and silver, may be obtained in exceedingly thin leaves, while others, like antimony and bismuth, appear to be perfectly unmalleable. Similar differences are noticeable in the ductility of the metals; some of them can be drawn out into very fine wire, while others are altogether destitute of ductility.

Even the property of opaqueness belongs only conditionally to the metals, for gold and silver are translucent in thin plates, the former transmitting green rays and the latter blue rays, though none of the other metals have been obtained in sufficiently thin leaves to allow of the transmission of light.

It will thus be seen that the properties of metals vary very much from those ordinarily ascribed to them, and the same must be said in regard to their fusibility. While some fuse at a low temperature—even below that of boiling water—others melt only at a red heat, a strong red, or a white heat. The temperatures corresponding to different colors are explained in the following table by Pouillet:

Incipient red heat	corresponds	to	977° F.
Dull red	"	"	1292° F.
Incipient cherry-red	"	"	1472° F.
Cherry-red	"	"	1652° F.
Clear cherry-red	"	"	1832° F.
Deep orange	"	"	2012° F.
Clear orange	"	"	2192° F.
White	"	"	2372° F.
Bright white	"	"	2552° F.
Dazzling white	"	"	2732° F.

Certain of the metals soften before actual fusion takes place, so that they can be hammered or welded into compact masses.

There are, however, some points in which all the metals to be here discussed agree.

They are distinguished by great weight, lead, iron, gold and platinum being representatives of those prominent in this respect.

They are, as a rule, very ductile bodies, copper, silver, gold, etc., being representatives of this group. Others like zinc, antimony, and bismuth, which have by some chemists been classed among the metalloids, show, however, a high degree of brittleness.

With the exception of mercury and gallium, they are all solids at the ordinary temperature, and become liquid only at higher temperatures.

They are, without exception excellent conductors of heat and electricity, that is, they rapidly absorb them, but just as rapidly yield them up again.

Finally it remains to be remarked that the metals show considerable differences in regard to specific gravity, ductility, conductivity, etc., which will be referred to in speaking of the special properties of the metals available for alloys.

b. Chemical Relations of the Metals.

Chemically, the metals are distinguished by their ability to form combinations with the non-metallic elements; the combinations with the oxygen of the air being especially energetic. The affinity of the different metals for oxygen, however, varies greatly, the majority of the metals used in ordinary life combining with it at an ordinary temperature. This phenomenon can be readily observed on the previously mentioned lump of lead. The fresh surfaces lose their luster by the lead combining with the oxygen from the air, which gives rise to a coating of oxide. Copper,

having less affinity for oxygen, remains bright for some time, and then acquires a brown-red coloring, which is also due to the formation of a layer of oxide. Many other metals remain bright at an ordinary temperature, and only lose their characteristic luster by oxidation taking place at a higher temperature—this last phenomenon being, for instance, observed with tin and antimonial metals which become oxidized by heating. In ordinary language all metals losing their metallic luster at an ordinary temperature or by heating are termed *base metals*, while the term *noble metals* is applied to those which have so little affinity for oxygen that they cannot be induced directly to unite with it even at high temperatures. The number of noble metals is very small in comparison with that of the base metals and of those more frequently used; mercury, silver, gold and platinum only can be actually counted among them.

From what has been said, it will been seen that the metals may be divided according to their behavior towards oxygen, such a division being in fact well supported, as we will have occasion to demonstrate in the course of our explanation.

In a chemical sense, the metals can be further divided with reference to certain physical properties into *heavy* and *light* metals. There is a series of metals whose specific gravity is so small that they float upon water, that of some of them being not greater than ordinarily exhibited by glass. Chemists term such metals light metals, in contradistinction to those which are distinguished by great weightiness.

The properties of the light and heavy metals allow, however, of an easy separation as regards their chemical relations, and, by taking these relations into consideration, the result will be a suitable division of the metals into determined groups which, together with their special properties, will be mentioned.

The metals belonging to the group of light metals have a very low specific gravity, which does not exceed four

(the weight of a volume of water being always taken as a unit). These metals find but a limited application by themselves, most of them having such strong affinity for oxygen as to be very speedily converted into oxide on coming in contact with the air. Only two of them, magnesium and aluminium, form an exception in this respect, and are, therefore, used in the arts and industries though the former only to a limited extent. According to their occurrence, these metals are divided into several groups, viz.: *Metals of the alkalies, metals of the alkaline earths, and metals of the earths.* To the *metals of the alkalies* belong *potassium, sodium and lithium.* Potassium and sodium are lighter than water, and lithium is only about one half as heavy. The metals of the alkalies are characterized by their strong chemical affinities for negative elements, and are therefore well adapted for withdrawing oxygen, sulphur, chlorine, etc., from combination with other elements. They belong to our most powerful reducing agents.

The metals of alkaline earths have nearly the same properties as the metals of the alkalies, but their affinity for oxygen, though very considerable, is somewhat less. Chemists include in this group *calcium*, occurring in gypsum, limestones and many other minerals; *barium*, contained in heavy spar; and *strontium*, the principal natural-occurring compounds of which are the sulphate, or *celestite*, and the carbonate, or *strontianite.* Like the alkali metals, the metals of the alkaline earths do not find a direct application in the industries, their great affinity for oxygen rendering such use impossible.

The metals of the earths occur in many minerals, and a large number of metals belonging to this group are known, but only two of them—*aluminium*, occurring in alum, clay, feldspar, and a large number of other minerals, and *magnesium*, found in dolomite, etc.—have any claim to our attention on the ground of their technical importance. Their affinity for oxygen is not so energetic as that of the

other metals of this group, since both can be kept in contact with dry air without entering into combination with oxygen, aluminium even retaining its luster for a comparatively long time.

All light metals have, however, the property of readily decomposing water, the metals of the alkalies and metals of the alkaline earths effecting this at an ordinary temperature. When a piece of potassium is thrown upon water, a vigorous development of hydrogen immediately takes place. The metal melts in consequence of the heat liberated by the chemical process, and the developed hydrogen ignites. The metal combines immediately with the oxygen to potassium oxide, which dissolves in water. After the combustion of the potassium, a colorless globule, consisting of the melted potassium oxide, floats upon the surface of the water. With a peculiar fizzing noise this globule suddenly bursts into pieces, which speedily dissolve in the water to potassium hydroxide.

The metals of the earths act less energetically on meeting with water, though they decompose it at a boiling heat; magnesium, for instance, when strongly heated in contact with air, burns freely, light and heat being developed.

The heavy metals, *i. e.*, those which are chiefly used in ordinary life, can, according to their chemical behavior, be brought into four well-defined groups, the group into which each metal is to be placed depending on its behavior in contact with steam or with water in the presence of an acid. In reference to this we distinguish the following groups:—

1. Metals which decompose water at the ordinary temperature in the presence of an acid, and which possess the further property of decomposing water at a higher temperature (at a red heat). To this group belong iron, zinc, nickel, cobalt, chromium, cadmium, tin and a few rarer metals.

2. Metals which decompose water at the temperature of

a red heat, but lack the property of decomposing water in the presence of an acid. Of the more important metals, only antimony and tungsten belong to this group.

3. Metals which are incapable of sensibly decomposing water either at a red heat or in the presence of an acid, and are entirely indifferent towards it at an ordinary temperature. The metals belonging to this group, of which bismuth, lead, copper and mercury are representatives, possess, however, the property of oxidizing when heated red-hot in contact with air.

4. Noble metals are, finally, such as do not combine with oxygen when strongly heated in contact with air, and at a red heat remain entirely indifferent towards water. Silver, gold, and platinum are the most important of the metals belonging to this group.

Besides the metals enumerated in the preceding groups, there are a number of others, which, according to their behavior, belong to one or the other. But, as previously mentioned, these metals are of no technical importance, being on account of their rarity too expensive to be used for industrial purposes. Moreover, it may here be remarked that among the enumerated metals are some, for instance, cobalt and tungsten, whose application in the industries is very limited, though they can he procured in large quantities. A more extensive use may, however, be found for them in the future, as has been the case with nickel, with which nothing could be done for a long time, but which is now used in large quantities for electro-plating and, in the preparation of very important alloys.

While certain metals possess the property of considerably hardening other softer and more ductile metals, certain non-metallic bodies exert a still greater influence upon the properties of a metal. It will, therefore, be necessary briefly to consider these bodies.

Carbon, sulphur, phosphorus and arsenic are the most prominent of the non-metallic bodies which are capable of

changing to a considerable degree the properties of a metal, and these bodies being much used for that purpose in the industries, we will have to consider their combinations with the metals, though they do not belong to the actual alloys.

The exceedingly great influence exerted by these bodies upon the properties of metals, even if admixed only in very small quantities, is best shown by the behavior of iron.

Pure iron, such as is used for piano strings or good shoe nails, is a metal of great hardness and extraordinary tenacity, which can only be fused at the highest temperature capable of being produced in our furnaces. It contains at the utmost one-half per cent. of foreign substances, consisting of varying quantities of manganese, silicon, and carbon. But iron containing a quantity of foreign substances amounting to 1½ per cent. of which carbon constitutes the greater portion, shows entirely different properties and is termed *steel.*

As is well known, the properties of steel are quite different from those of iron. It is harder, more elastic, and more tenacious, and fuses somewhat more readily. By still further increasing the carbon in the iron to about three per cent., we have what is known as cast-iron. It is more fusible than steel, but brittle, and cannot be worked under the hammer (it cracks). According to the content of carbon, it shows a gray to nearly white color (gray and white cast-iron) and a crystalline structure.

A content of sulphur or phosphorus exerts a still greater effect upon the properties of iron than one of carbon. Iron, containing but a few thousandths of sulphur, can only be worked in the heat; if hammered in the "cold" it cracks; it having become what is termed "cold-short," *i. e.*, brittle when cold. With a still smaller content of phosphorus, the iron cannot be worked with the hammer, even at red heat, and at a white heat cracks under the hammer; it having become "red-short" or "hot-short." The admixture of these bodies (carbon, sulphur, and phos-

phorus) with the metals is frequently an unintentional one, it being due to the nature of the ores used.

Before proceeding with the description of the properties of the alloys and the manner of their manufacture, it will be convenient in order to avoid unnecessary repetition later on to give a short sketch of the special properties of the separate metals. As previously mentioned, some metals can be readily combined according to certain fixed proportions. In such case we have not alloys in the actual sense of the word (*i. e.*, mixtures of metals), but rather chemical combinations.

By a chemical combination is understood the union of two or more simple elements in unalterable proportions or multiples thereof. Each element possesses the property of combining with the other according to a proportion of weight admitting of no variation whatever, and the quantity of weight which enters into the combination, and is capable of so completely invalidating the properties of the other bodies that, so to say, a new body is formed, is termed the atomic or indivisible weight. The names of the most important elements are given in the annexed table, together with their symbols and atomic weights, which express the proportions in which they combine together, or simple multiples of those proportions. The symbols are formed of the first letters of their names derived either from the Latin or Greek. Hydrogen is, for instance, represented by the letter H, from the word *hydrogenium;* Oxygen by O from *oxygenium;* Silver by Ag, from *argentum*. If Latin or Greek names of several elements have the same first letters, the first letter serves only for the designation of one of these elements, while for the other elements the first letter is supplemented by an additional characteristic letter. Thus, for instance, Boron is represented by the letter B; Barium by Ba; Bismuth by Bi; Bromine by Br.

Name of Element.	Symbol.	Atomic Weight.	Name of Element.	Symbol.	Atomic Weight.
Aluminium	Al	27.04	Magnesium	Mg	23.94
Antimony	Sb	119.6	Manganese	Mn	54.8
Arsenic	As	74.9	Mercury	Hg	199.88
Barium	Ba	136.9	Molybdenum	Mo	96.0
Bismuth	Bi	207.5	Nickel	Ni	58.6
Boron	B	10.9	Nitrogen	N	14.01
Bromine	Br	79.76	Osmium	Os	191.0
Cadmium	Cd	111.7	Oxygen	O	15.96
Calcium	Ca	39.9	Phosphorus	P	30.96
Carbon	C	11.97	Platinum	Pt	194.31
Chlorine	Cl	35.4	Potassium	K	39.03
Chromium	Cr	52.4	Selenium	Se	78.87
Cobalt	Co	58.6	Silicon	Si	28.0
Copper	Cu	63.18	Silver	Ag	107.06
Fluorine	Fl	19.06	Sodium	Na	23.0
Gallium	Ga	69.8	Sulphur	S	31.96
Gold	Au	196.2	Tin	Sn	117.35
Hydrogen	H	1.0	Titanium	Ti	48.1
Indium	In	113.4	Tungsten	W	184.0
Iodine	I	126.54	Uranium	U	239.5
Iron	Fe	55.88	Vanadium	V	51.1
Lead	Pb	206.4	Zinc	Zn	64.88

The symbols not only represent the elementary bodies but also their fixed quantities by weight, namely their atomic weights, so that, for instance, the symbol Ni means 58.6 parts by weight of nickel.

Compounds produced by the union of the elements are represented by placing their corresponding symbols together and designating them *chemical formulas*. Thus, for instance, common salt consists of one atom sodium (Na) and one atom chlorine (Cl) and hence its formula has to be written NaCl. The latter shows that one molecule of common salt consists of 23 parts by weight of sodium and 35.4 parts by weight of chlorine, which together form 58.4 parts by weight of common salt. If several atoms of an element are present in a compound, this is denoted by numbers which are attached to the symbol of the atom. Water consists of two atoms hydrogen (H) and one atom oxygen (O), and hence its formula is H_2O, which shows that two parts by weight of hydrogen, together with 15.96 parts by weight of oxygen form 17.96 parts by weight of water.

CHAPTER III.

SPECIAL PROPERTIES OF THE METALS.

a. *Metals of the alkalies.* The strong attraction of the metals of the alkalies, and especially of potassium, for oxygen, makes it impossible for them to occur in the free state in nature. *Potassium* is chiefly found in the mineral kingdom in combination with oxygen and silica as a silicate, and in this form is a constituent of potash feldspar; it also occurs, united with chlorine, as potassium chloride.

Nearly all land plants require potassium compounds for their growth, and even for their existence. These potassium compounds are absorbed by their roots and converted in their structure into potassium salts of organic acids. When the plants are burned nearly the whole of the potassium which they contain remains behind as potassium carbonate. This was formerly the material from which potassium compounds were almost exclusively prepared.

Sodium which is closely allied to potassium is also found in nature in the form of a double silicate of aluminium as soda feldspar or albite. It further occurs as the mineral cryolite, which is worked both for soda and alumina. But by far its most important natural compound is the chloride—common salt or rock salt.

Both these metals can be prepared in large quantities by treating their carbonate—potassium carbonate or sodium carbonate—with charcoal and chalk in iron retorts at a white heat. They are brilliant-white with a high degree of luster. At an ordinary temperature they are soft and may be easily cut with a knife. They have a very low melting point, potassium melting completely at 144.5° F., and sod-

ium at 207.5° F. Exposed to the air both metals rapidly oxidize, and must, therefore, be preserved under a fluid containing no oxygen (petroleum). In consequence of these properties neither potassium nor sodium can be used in the industries, and serve only for the indirect preparation of some metals. For instance, by a combination of alumina and chlorine with potassium or sodium, the latter, in consequence of their stronger affinity for chlorine, withdraw it from the combination, whereby metallic aluminium is liberated. Several other metals can be prepared in a similar manner.

Lithium is a rare element, and of no technical importance. Some of its compounds find extensive use in medicine. It is widely distributed in nature and is found, though always in small quantities, in several minerals, as well as in numerous mineral springs.

b. Metals of the alkaline earths. To this group belong, besides calcium, occurring in limestone, gypsum, and several other minerals, barium and strontium. The affinity of these metals for oxygen is so great, that like potassium and sodium, they have to be kept under petroleum, and are not used in the form of metals in the industries.

c. Metals of the earths proper. The most important of this group is *aluminium* (Al; atomic weight 27.04). It is a white metal very nearly approaching silver in appearance. It melts at a red heat, about 1300 F., but will not vaporize. It changes very little at the ordinary temperature, or even when moderately heated, but if heated in a stream of oxygen it burns brightly. Nitric acid does not effect aluminium, sulphuric acid only dissolves it on boiling, while it is readily soluble in hydrochloric acid. But the action of these acids is greatly modified by the purity of the metal and also by the mechanical conditions under which the metal has been prepared, hammered aluminium being least attacked, rolled metal next, and then the drawn metal, while cast metal is much more easily attacked than either.

Caustic alkalies in solution readily attack aluminium; in ammonia it is turned gray, but does not lose strength or weight. Chlorine, bromine, iodine and fluorine attack aluminium and corrode it. It is, however, not affected by sulphuretted hydrogen or other sulphur vapors.

The *specific heat* of aluminium is, according to Richards, 0.2270, water being 1.0000, that is, the same quantity of heat that would raise a mass of aluminium 0.2270 of a degree C., would raise the same mass of water 1.0000 full degree C.

The *conductivity of heat*, taking silver as 100, is 38 for unannealed wire of 98.52 per cent. aluminium, and 38.90 in the same wire annealed. The following table enables us to compare its conductivity with that of other metals:

Silver, 100.	Tin, 14.5.
Copper. 73.6.	Iron, 11.9.
Gold, 53.2.	Steel, 11.6.
Annealed aluminium, 38.9.	Platinum, 8. 6.
Unannealed aluminium, 38.0.	Bismuth, 1.8.

The *electric conductivity* of aluminium, as compared with copper, has been determined by Mr. C. K. McGee, of the University of Michigan. He found that in an aluminium unannealed wire 0.0325 inch in diameter the electrical resistance was 0.05749 "legal ohms" of one yard, while that of pure copper wire of same diameter was only 0.03150; temperature 57° F. In the annealed aluminium wire of same dimensions it was 0.05484. The aluminium was 98.52 per cent. pure. Pure aluminium shows no polarity. An ingot of aluminium containing 1.5 per cent. iron showed a very faint polarity; with two per cent. iron the polarity was distinct and very decidedly marked.

Aluminium has become important only within a few years past. Forty years ago it was as much a chemical curiosity as any one of the rare metals is to-day. Through the efforts of H. St. Claire Deville it first acquired a commercial character, and its extraction was transferred from

the sphere of laboratory experiment to become a metallurgical process.

Aluminium is the most widely distributed metal on earth. It is never found in the metallic state, but always combined with oxygen, and in this form, Al_2O_3, is the basis of many of the commonest rocks and the chief constituent of most clays. It is found in porphyries, igneous rocks, and in connection with quartz in granite, gneiss, mica, schist, syenite, and some sandstones, while sapphire and ruby consist exclusively of it.

Aluminium was formerly prepared as follows: The double chloride of sodium and aluminium was first prepared by heating a mixture of alumina, common salt and charcoal in a stream of chlorine. 100 parts of the sublimed double chloride were next mixed with 35 parts of sodium and 40 parts of cryolite (to serve as a flux), and heated on the hearth of a reverberatory furnace. The aluminium was then reduced and collected on the hearth under the fused slag.

However, so long as aluminium could be prepared only by the reduction of its chloride by means of sodium, its use for other purpose, besides the manufacture of expensive fancy articles, was out of the question. But since the efforts to reduce Al_2O_3 by means of a current of electricity have been successful, the price of the metal has been sufficiently low to allow of its being used for technical purposes.

The principle of reduction by electrolysis is that alumina is decomposed in the presence of a melted fluoride by the electric current, and metallic aluminium is liberated. The process of manufacture, as conducted by the Pittsburgh Reduction Company of Pittsburgh, Pa., is the invention of Charles M. Hall, and consists essentially in dissolving alumina in a melted bath composed of the fluoride of some metal more electro-positive than aluminium; passing an electric current through the melted mass, and the production of aluminium by electrolysis of the dissolved alumina;

the fluorides of sodium and calcium with the fluoride of aluminium being the preferable salts used in the melted bath, although the fluorides of aluminium and sodium have been used successfully alone, without the fluoride of calcium, in some of their commercial work. The fluoride bath material, when melted, is almost permanent; the only loss being small mechanical loss of material sticking to the pokers and ladles, and a very small loss from volatilization, when the process is working correctly. Fresh fluoride bath material is more or less impure, containing oxides of silicon and iron, in the form of quartz, sand and spathic iron, and these metals are alloyed with the first aluminium produced in the new bath, as all of the silicon and iron are reduced before almost any aluminium is reduced, and the first metal produced contains nearly all these impurities from the melted fluoride salts.

Commercial aluminium is frequently contaminated by foreign metals. The following analyses show the composition of various kinds of commercial aluminium:

	I.	II.	III.	IV.	V.	VI.	VII.	VIII.
Aluminium	88.35	92.969	96.253	92.00	92.5	96.16	94.7	97.20
Silicon	2.87	2.149	0.454	0.45	0.7	0.47	3.7	0.25
Iron	2.40	4.882	3.293	7.55	6.8	3.37	1.6	2.40
Copper	6.38	——	——	——	——	——	——	——
Lead	trace	——	——	——	——	——	——	——
Sodium	——	trace	trace	——	——	——	——	——

A content of iron in aluminium is very injurious, it rendering the metal uncommonly hard. However, the varieties of aluminium prepared by electrolysis are, as a rule, quite pure, copper being the chief impurity contained in them. The greatest value of aluminium, perhaps, is in the wonderful alloys it is capable of producing. They are exceedingly numerous, and the range of proportions of the ingredients to produce useful alloys is very wide. In a general way, aluminium may be said to improve the qualities of

every metal to which it is added in small quantities; increasing the strength. The most important alloys are the alloys with copper. These form a striking series, of which the alloy of 10 per cent. of aluminium and 90 per cent. of copper is the most prominent. These and other alloys of aluminium will be described later on.

Magnesium (Mg; atomic weight 23.94). This element, in a state of combination, occurs widely distributed, and is found in a great variety of minerals. It is met with as hydrate, carbonate, chloride, bromide, sulphate, phosphate, and nitrate; it exists in large numbers of bodies in combination with silica, as, for example, in hornblende, augite, talc, soapstone, asbestos, etc. It is found in many mineral waters; sea water containing considerable quantities of the chloride and sulphate.

The metal was isolated by Davy in 1808, and is now prepared on a considerable scale, either by separating it from its chloride with the assistance of the electric current, or from its double combinations of magnesium chloride with calcium chloride, or of magnesium fluoride with sodium fluoride by means of sodium.

Magnesium, in a pure state, possesses a silvery white color and acquires a high luster by polishing. Its specific gravity is 1.743. Its hardness is nearly that of calcite. At the ordinary temperature it is somewhat brittle, but at a red heat it is malleable, and scarcely more ductile than zinc. Recent experiments have shown that its tensile strength is higher than that of aluminium and brass, and nearly equal to that of bronze or of Delta metal. In dry air it does not change and does not lose its luster; in moist air it soon becomes coated with a white layer of magnesium hydrate; but as the latter is very coherent, this alteration does not extend beyond the surface. Its fusing point is generally given at about 932° F., but, according to Victor Meyer, it is much higher. It fuses with greater difficulty than sodium bromide, and is nearly as fusible as

sodium carbonate, the latter melting at 1482° F. When heated to somewhat above its fusing point it burns, similar, to zinc, with an intensely bright white light, rich in chemically active rays. The preparation of magnesium alloys is connected with great difficulties on account of the oxidizability of the metal. The alloys may be obtained by melting the metals together in a current of hydrogen, or under fluxes of fluorspar and common salt or cryolite; or, according to White, the other constituent metal is fused and the magnesium quickly immersed by means of tongs. According to Parkinson, magnesium furnishes alloys with sodium, mercury, tin, cadmium, bismuth, lead, zinc, antimony, silver, platinum, gold, copper and aluminium; it alloys also with copper and nickel when combined, but not with iron, cobalt or nickel. The color of the white metals combined with magnesium is not essentially affected, except when the content of magnesium is very large, as is certain alloys with tin, silver and lead. All magnesium alloys are very brittle, tarnish more or less in the air, and decompose water more or less readily.

With potassium and sodium, magnesium yields malleable alloys which decompose water at the ordinary temperature. Eighty-five parts tin and 15 parts magnesium give a lavender-blue, hard, brittle alloy, which also decomposes water.

With mercury magnesium does not amalgamate at the ordinary temperature, but by shaking magnesium with mercury in dilute sulphuric acid, amalgamation takes place (Hartley and Phipson, and J. Parkinson). By heating magnesium with mercury to nearly the boiling point of the latter, amalgamation also takes place under violent reaction Such an amalgam, containing 1 part magnesium and 200 parts mercury, on exposure to the air becomes immediately dull and swells up; it decomposes water as vigorously as sodium amalgam (Wanklyn and Chapman). Magnesium also combines with lead and zinc, alloys with 5 to 20 per

cent. being suitable for fireworks, and may, for instance, in the form of powder, be added to rocket charges. With thallium, magnesium combines in all proportions, alloys with 5 to 25 per cent. thallium, burning with a steady and bright flame, whereby the intense magnesium light suppresses the green color of the thallium, which is only slightly noticeable even with 50 per cent. thallium.

According to Holtz, expectations regarding the technical availability of magnesium alloys have not been fulfilled. Iron, steel, copper, brass and bronze are not rendered malleable and softer by an addition of magnesium, but brittle.

d. Heavy metals, To this group belong the metals of the most importance to the industries. They are divided according to their chemical behavior into several sub-divisions, named after the most common metal occurring in them. We speak, therefore, of a zinc group, an iron group, a silver group, etc., and this division will here be retained, it being very suitable to make clear the connection existing between certain minerals.

1. *Iron Group.*

(Iron, Manganese, Cobalt, Nickel, Chromium, Uranium.)

Among the metals belonging to this group, iron is most widely distributed and most frequently used. It forms, however, but a small number of alloys available in the industries. Nevertheless, on close examination it will be found that many alloys contain a small quantity of iron, which, however, has not been added intentionally, but is simply a contamination of the metals constituting the alloy. But, as we shall see later on, a very small quantity of a metal frequently suffices to exert considerable influence upon the physical properties of an alloy.

Iron (Fe., atomic weight 55.88). Native iron is of exceedingly rare occurrence, but it enters into the composition of those curious stones which have fallen to the earth

from space, and are known as meteorites. All iron prepared on a commercial scale contains carbon, the purest being wrought iron with about 0.15 per cent. carbon, then steel with from 0.15 to 1.5 per cent., and cast-iron with upwards of 1.5 per cent. In a general way it may be said that the properties of the various grades of iron depend upon the varying proportions of carbon present, and hence, in this sense, iron may be considered an alloy with carbon. Silicon and manganese also are sometimes present, not as incidental, but as intentional constituents. The preparation of such varieties of iron, however, belongs more particularly to the metallurgy of iron proper.

Chemically pure iron may be obtained by reducing peroxide of iron by hydrogen at a red heat, or by remelting the purest varieties of malleable iron with an oxidizing flux in order to remove the last traces of combined carbon. The physical properties of the metal vary very considerably according to the means adopted for its production. When obtained by reducing peroxide of iron by hydrogen at the lowest possible temperature at which the change can be effected (according to Magnus between 600° and 700° F.) it forms a dark-gray powder, which combines energetically with oxygen, taking fire spontaneously when slightly heated and thrown into the air. When, however, the reduction takes place at a higher temperature, the metallic powder agglutinates to a sponge of filamentous texture, a silvery-gray color, and metallic luster which is no longer pyrophoric.

Larger and more compact masses may be obtained by removing the last traces of carbon and other foreign substances from the purest commercial wrought iron in the following manner: A small quantity of good wrought iron such as pianoforte wire or Russian black plate, cut up into small pieces, and either rusted by exposure to steam or mixed with about 20 per cent. of pure peroxide of iron, is to be melted under glass free from metallic oxides, in a

refractory crucible, at a strong white heat, the operation requiring about an hour's full heat of a good wind furnace. The small quantity of carbon present in the metal is expended in reducing a portion of the sesquioxide, the remainder passing into the slag. The result is a brilliant well-melted button of metal, which exhibits a decidedly crystalline structure, similar to that observed in meteorites when the latter are treated with an etching liquor, and is somewhat softer, but less tenacious than the iron originally employed. This last method of producing pure iron is recommended for experimenting in the preparation of alloys with iron, though, if too troublesome, the best quality of pianoforte wire will answer the purpose.

Iron oxidizes very readily; in a damp atmosphere the rust has a very destructive action, and necessitates the employment of varnishes and other preservative coatings. In the melted state or at a red heat, iron in contact with the air oxidizes rapidly, and acids attack it and dissolve it with ease.

Iron alloys readily and in all proportions by weight with manganese, chromium, tungsten, titanium, vanadium, nickel, cobalt, gold, platinum, aluminium, antimony, tin; with greater difficulty with larger quantities of copper, though smaller quantities of the the latter are readily absorbed by iron, and smaller quantities of iron by copper. It alloys with zinc only in limited proportions. Acicular zinc crystals contained, according to Erdmann, in addition to 93.2 per cent. zinc, 6.5 per cent. iron and 0.3 per cent. lead. Small prismatic crystals, examined by Abel, contained. 7.45 per cent. zinc besides 91.80 per cent. iron and 0.75 per cent. lead, On the other hand, a more refractory and specificially heavier alloy containing as a rule 3 to 5 per cent. of iron is formed on the bottom of iron pots in which zinc is for a long time kept in a liquid state.

In refining zinc, for which purpose it is kept for a long time in a liquid state in a reverberatory furnace or pot, an

alloy is separated which may contain 6.3 per cent. of iron, and by dissolving iron in melted zinc heated to a red heat, an alloy with 8.5 per cent. of iron may be produced. Since on being more strongly heated the zinc volatilizes, it may be assumed that this is the limit of iron which can be taken up by zinc. However, according to Snelus, 12 per cent. of iron may be dissolved in zinc if the iron be added in the form of powder, and the solubility is increased by the addition of arsenic to the zinc. With 2.25 per cent. arsenic the alloy may take up 14.15 per cent of iron.

Iron also alloys only to a limited extent with bismuth, and, under ordinary conditions not at all with lead and silver. In iron blast furnaces in which plumbiferous iron is worked, the lead together with all the silver is obtained completely separated from the iron.

Iron alloys are of no technical importance, except the combinations of iron with nickel, tungstem, chromium, vanadium and manganese, which play a role in working crude iron and especially in the preparation of steel; further combinations with tin and zinc which have to be considered in tinning and galvanizing iron; and finally in the preparation of ferriferous brass (Delta metal) and of iron containing aluminium (mitis castings).

Manganese (Mn; atomic weight 54.8) is so intimately associated with iron that it is rare to find an ore of it that does not contain the other in greater or less proportion. There are many compounds of manganese, one of the most commonly occurring being the black oxide MnO_2, the mineralogical name of which is pyrolusite. Manganese having an extraordinarily great affinity for oxygen is never found in nature in a metallic state. Although actual manganese ores in larger quantities do not occur in many localities, the element is very widely distributed, it accompanying nearly everywhere iron in ores and rocks; it is found in every soil, and passes from it into plants and into animal substances (blood, urine, liver, excrements); it oc-

curs in wine, in sea and mineral waters, in meteorites, in the solar spectrum, etc.

Metallic manganese was first extracted, in 1774, by Gahn. It may be obtained by reducing the dioxide MnO_2 or the carbonate $MnCO_3$ with charcoal or soot at a very high temperature. The fused mass, which is combined with a little carbon (as in cast iron) is freed from its carbon by reheating with manganese carbonate. As thus obtained the metal has a grayish-white color and a fine-grained structure. It is much harder than wrought iron, very brittle, and feebly attracted by the magnet. It rapidly oxidizes when exposed to air. Its specific gravity is 8.013. It fuses only at the highest temperature of a blast furnace, and is rapidly attacked by dilute mineral acids, hydrogen being evolved.

Manganese readily unites to alloys with many metals. The most important of these alloys for technical purposes are ferro-manganese, ferro-silicon manganese and cupro-manganese, the latter, amongst others, being used for the preparation of manganese-bronze, manganese-German silver, and manganese-brass.

Cobalt (Co; atomic weight 58.6). Compounds of cobalt appear to have been known to the ancients and used by them in coloring glass. The metal itself was first isolated by Brand in 1733. Metallic cobalt is occasionally found in meteoric iron associated with nickel and phosphorus. Its principal naturally occurring compounds are the arsenide, *smaltine*, or *tin-white cobalt; cobalt bloom* or *erythrine*, and *cobalt glance*. The pure metal is unalterable in air, even when moist, of a red-white color, very difficult to fuse, highly malleable and ductile, and capable of taking a polish; its specific gravity is about 8.9. It is slightly magnetic, and preserves this property even when alloyed with mercury. It bears in many respects a close resemblance to nickel, and is often associated with the latter in nature. It is not used by itself, and only very seldom as an intentional

addition to alloys. The protoxide is used in the color industry, the colors prepared from it being much employed in painting glass and porcelain.

Cobalt alloys more readily with copper than with iron, and gives alloys which melt at a temperature near the fusing point of copper, are ductile, and by repeated heating can be worked under the hammer. According to Wiggin, cobalt-bronze possesses all the properties of the pure metal without its high price. According to Guillemin, alloys of copper with 1 to 5 per cent, cobalt are red, very ductile and tenacious, and possess a tensile strength of 88 lbs. per 0.001 square inch. Knoop uses an alloy of 100 parts of iron aud 5 to 10 cobalt for pressed glass moulds.

Nickel (Ni; atomic weight 58.6). This metal was discovered in 1751 by Cronstedt, in the arsenide NiAs, a copper-colored mineral termed Kupfernickel (*i. e.*, false copper) by the German miners. This compound, together with the impure arsenide termed "speiss" formed at the bottom of the melting pots in the manufacture of "smalt," constitute the principal sources of nickel in Europe. Nickel ores are found in France, Sweden, Cornwall, Spain, Germany, New Caledonia, Canada, and in some localities in the United States, the largest and most extensive deposits being those of New Caledonia and at Sudbury, Canada. The preparation of metallic nickel is connected with many difficulties. It is generally found in commerce in the form of small cubes of a dull gray appearance. By melting these cubes at a very high temperature, the metal is obtained as a silver-white mass of considerable hardness, which takes a fine polish and is unalterable in dry air. It is slightly magnetic at ordinary temperatures, but temporarily loses this property on heating. It specific gravity is greater than that of iron, being 8.3 to 8.9, and with about an equal fusibility is far less subject to oxidation and corrosion. Its oxide is white, and defaces the polished metal comparatively little, and is easily removed. Nickel can be either cast or forged,

but is mostly used in preparing alloys or for electroplating more oxidizable metals.

The malleability of nickel allows of its being chased as are silver and gold, and with the result of greater luster, while the qualities of brilliancy, hardness and durability, whether used solidly or in electroplating, make it very suitable for table service.

Dr. Fleitman, of Iserlohn, has devised a simple and successful process of refining and toughening nickel, which is now very largely used. It produces a homogeneous metal, from which castings may be made with much less liability to the presence of blow-holes than with other methods. Fleitman's procedure consists in adding to the melted charge in the pot, when ready to pour, a very small quantity of magnesium. The magnesium is added, in very small portions at a time, and stirred into the charge. About one ounce of magnesium is found to be sufficient for purifiying 60 lbs. of nickel. The theory of the operation is that the magnesium reduces the occluded carbonic oxide, uniting with its oxygen to form magnesia, while carbon is separated in the form of graphite. The nickel refined by this method is said to become remarkably tough and malleable, and may be rolled into sheets and drawn into wire. Cast plates (intended for anodes in nickel-plating) after reheating, can be readily rolled down to the required thickness, which greatly improves them for plating purposes, as they dissolve with greater uniformity in the plating bath. Nickel so heated may be rolled into sheets as thin as paper, and has been successfully welded upon iron and steel plates.

Nickel alloys completely with copper, iron, manganese, zinc, tin, silver and cobalt, probably also with gold; incompletely, or not at all, with lead. Some of the nickel alloys possess properties which, for certain purposes, render them almost indispensable. The alloys known as argentan, German silver, China silver, similor, argent Ruolz, etc., are

prepared with the assistance of nickel. For coins, nickel appears to have been used in very ancient times, for, according to Moulan, Euthydemus King of Bactria, ordered, in 235 B. C., coins to be struck of an alloy containing 77 to 78 parts copper and 22 to 23 parts nickel. Switzerland commenced nickel coinage about 1850, and the United States in 1857. The subject of nickel-steel alloys was first called attention to by Mr. James Riley, of Glasgow, in a paper read by him before the British Iron and Steel Institute, at their meeting in May 1889. Since then nickel-steel has become of great importance for the manufacture of armor-plates, with $3\frac{1}{2}$ to 4 per cent. of nickel. Such plates present at least the same resistance to the penetration of shot as compound plates, but are less inclined to show cracks and flaws. To increase their tenacity the armor-plates contain, as a rule from 1 to 5 per cent. nickel. At the Bethlehem Iron Works armor-plates with $3\frac{1}{2}$ per cent. nickel are produced. A nickel-steel block weighing 90,000 lbs. has been cast at these works.*

Chromium (Cr.; atomic weight 52.4). This is a comparatively rare metal and only occurs in nature in combination with other elements, the chief ore being chrome-iron stone, FeO,Cr_2O_3, which occurs massive in various parts of the world. It is isomorphous with magnetic oxide of iron; it has a brownish-black color and sub-metallic luster. The metal is obtained by the reduction of its oxide or chloride, or by the electrolysis of its chlorides, when chromium separates out in brittle glistening scales. Its color is tin-white, and it has a specific gravity of 6.81. It melts with greater difficulty than platinum and is only slowly oxidized when heated in air. The fused metal is said to be as hard as corundum. Chromium is used in the form of an alloy with iron and carbon, forming a hard, white and brilliant steel.

*Iron, 1891, No. 989.

Uranium (U; atomic weight 239.5). This element is not found free in nature. It occurs chiefly as the oxide: $U_3O_8 = UO_2,2UO_3$, in the mineral pitchblende. The metal may be obtained by fusing uranous chloride with sodium, best in an iron crucible, and then forms either a black powder, or a hard metallic button of a gray color. It melts at a red heat and has a specific gravity of 18.7.

Uranium has been recommended for the manufacture of uranium steel, it being claimed that an addition of a very small quantity of the metal increases the elasticity and at the same time the hardness of the steel, making it especially suitable for casting ordnance.

Among the metals belonging to the iron group, nickel is the most important for our purposes, on account of the numerous alloys which can be prepared with its assistance. Among the other metals iron is of some importance, small quantities of it, as previously mentioned, being frequently met with as accidental impurities in many alloys.

2. *Zinc Group.*

(Zinc, Cadmium, Indium, Gallium.)

Zinc (Zn; atomic weight 64.88). The most valuable zinc ore is the native carbonate or *calamine*, which, together with the sulphide or *blende*, constitutes the principal source of the zinc of commerce. Zinc ores occur abundantly in the United States, the best being obtained in New Jersey, Pennsylvania and Virginia, and in a line of deposits running through West Virginia and the Middle States, across to Illinois, Missouri and Kansas, and north into Wisconsin. Large quantities are mined in Missouri and other parts of the country, and in Europe. Zinc in the metallic state was not familiar to the ancients, although they were accustomed to use its ores in the manufacture of brass. The alchemist Paracelsus, in 1541, makes mention of metallic zinc, but it was doubtless known before his time, and was probably discovered by Albertus Magnus, who called it *marchasita*

aurea. It became a regular article of manufacture about 1720, in Germany, and in England fifteen or twenty years later. It has been regularly manufactured in the United States since about 1850, first in New Jersey and later on in a number of other localities.

Metallic zinc is a bluish-white metal known to the trade as "spelter." Its properties are rather peculiar, and, as it plays an important part in the manufacture of alloys, will have to be more closely considered. Zinc is hard and brittle, and, when fractured, exhibits a highly crystalline structure. It experiences very little alteration in the air, becoming very slowly coated with a permanent and impenetrable coating—a basic carbonate—which renders it very valuable for sheathing and for work exposed to the weather. Zinc can be cast, and makes good architectural ornaments. The castings made at a high temperature are brittle and crystalline; when cast at near the melting point they are comparatively malleable. Zinc is hardened by working, and must be occasionally annealed.

Zinc at an ordinary temperature shows a considerable degree of brittleness, and if a piece of sheet-zinc be several times bent backward and forward it soon breaks. By heating the zinc, however, to between 230° and 302° F., it acquires a considerable degree of ductility, and can be rolled out into thin sheets. At a still higher temperature it again becomes brittle, and when heated at 392° F., can readily be reduced to a powder. Its specific gravity varies between 6.9 and 7.2, the latter being that of the rolled metal. Zinc melts at 773.5° F. By heating the fused metal but a little above its melting point with the admission of air, it ignites, and burns with a bright, white flame to a very spongy, pure, white powder, forming the oxide known under the name of "zinc white," and employed as a pigment. It is chiefly valued for its permanency, as it is not blackened by exposure to sulphuretted hydrogen like white lead. At a white heat zinc boils and can be distilled.

At temperatures which do not materially exceed its fusing temperature (806° F), zinc alloys only to a limited extent with bismuth. According to Matthiessen, zinc dissolves at the utmost 2.4 per cent. of bismuth, and bismuth, at the utmost, 14.3 per cent. of zinc. On the other hand it has been found by W. Spring and L. Romanoff that at 1562° F. both metals dissolve in every desired proportion.

With lead zinc alloys only to a limited extent. Commercial zinc obtained by distillation from plumbiferous ores may contain up to 5.6 per cent. of lead. If, however, for the purpose of refining, such zinc be kept liquid for some time, a portion of the dissolved lead separates in the form of lead-zinc with about three per cent. of zinc and, being the heavier constituent, deposits on the bottom. The remaining zinc then contains, as a rule, not much over one per cent. of lead.

With silver zinc alloys, however, more readily and this behavior of zinc, on the one hand, towards silver and, on the other, towards lead, is made use of in smelting works to withdraw the content of silver from argentiferous lead. Zinc is added to the melted lead whereby an insoluble zinc-silver alloy is formed. This rises to the surface and is skimmed off for further working.

Zinc alloys readily with copper, tin, gold, nickel and antimony. Its behavior towards iron has previously been referred to.

Cadmium (Cd; atomic weight 111.7), occurs in nature in a few minerals, for instance, combined with sulphur in greenockite. Compounds of this metal frequently occur, associated with zinc ores; as cadmium is more volatile than zinc, it is mainly found in the first portion of the distilled metal when the ores are reduced by carbon. Cadmium was discovered by Strohmeier in 1818.

Pure metallic cadmium is obtained by precipitating from a solution of zinc containing cadmium in sulphuric or hydrochloric acid, the cadmium by pure zinc, or by dissolv-

ing commercial cadmium in sulphuric or hydrochloric acid, precipitating cadmium sulphide by sulphuretted hydrogen, dissolving the thoroughly washed cadmium sulphide in concentrated hydrochloric acid, precipitating the solution with excess of ammonium carbonate, and igniting the washed and dried cadmium carbonate with $\frac{1}{10}$ pulverized coal in a glass or porcelain retort in order to distil over cadmium. Reduction may also be affected with hydrogen. Dissolve commercial, zinciferous cadmium in hydrochloric acid, so that a small quantity of the metal remains undissolved, filter the dilute solution, add ammonia in excess, filter again, and add potash solution as long as turbidity results. Wash the precipitate of cadmium oxyhydrate, dry, dehydrate it completely by continued heating in a covered crucible at 572° F., and convert into brown cadmium oxide, which is reduced.

Cadmium is a silver-white crystalline metal and possesses the same property as tin, of giving out a crackling sound when bent. It is quite soft, but a small content of zinc makes it brittle. On account of its ductility it can be readily rolled or beaten into sheet and very thin foil, the latter being more coherent than tin foil and having, similar to lead foil, a dull sound. By rolling, cadmium does not completely lose its crystalline structure. Its specific gravity is 8.6, it melts at 608° F., and boils at 1580° F. It is readily dissolved by mineral acids; contact with platinum preserves it from the action of strong nitric acid.

With gold, platinum, copper and partially with mercury, cadmium yields brittle alloys; but with lead, tin, and in certain proportions with silver and mercury, very ductile combinations, for instance, 1 and 2 parts of silver with 1 cadmium, while an alloy of 2 parts cadmium and 1 silver is brittle. Cadmium 1 part and mercury 1, gives a very plastic, malleable amalgam, while that obtained from cadmium 1 part and mercury 2, is just as malleable and not so tough. According to de Souza, cadmium amalgam retains mercury at

680° F., but no longer at 824° F. Alloys of cadmium with bismuth and lead are readily fusible, and those of tin and cadmium very ductile. By combining cadmium with tin, bismuth and lead in certain proportions, alloys are formed which on account of their low fusing points, find many technical applications.

Indium (In; atomic weight 113.4). This rare metal, discovered in 1863 by Reich and Richter in the zinc blende of Freiberg, is also found in very small quantities in a few other zinc ores, and when these are worked for zinc alloys itself with the metal. Indium is a white lustrous metal of specific gravity 7.4, and melts at 349° F. It remains unchanged in the air, but burns when heated to redness with a violet light, and producing brown vapors. It dissolves slowly in hydrochloric or dilute sulphuric acid, but easily in nitric acid.

Gallium (Ga; atomic weight 69.8). This element, discovered in 1875 by Lecoq de Boisbaudran, is contained in some samples of blende found in the Pyrenees, but only in extremely minute quantities—about 0.002 per cent. It is a white lustrous metal of low melting-point—86° F.—when once melted it remains liquid, like mercury, even at 0°. Its specific gravity is 5.9. The metal remains unaltered in the air, and only becomes covered with a thin layer of oxide when heated nearly to redness. It is not attacked by water at the ordinary temperature, but dilute hydrochloric acid as well as the alkalies dissolve it with evolution of hydrogen.

Thus far only alloys of gallium with aluminium and iridium have been prepared.

3. *Tungsten Group.*

(Tungsten, Molybdenum, Vanadium.)

As regards their properties the three metals forming this group approach the iron group.

Tungsten (W; atomic weight 184). This element resem-

bles molybdenum in many respects, but is distinguished from it by the high specific gravity of the free element and of its compounds. Tungsten never occurs free in nature, and its compounds are only found in small quantities. The best known of the tungsten minerals are *wolfram*—ferrous and manganous tungstate—and *scheelite*—calcium tungstate—the former of a dark-gray color, with a specific gravity of 7.5, the latter consisting of white crystals also remarkable for its high specific gravity.

Tungsten prepared by the reduction of tungstic anhydride in a stream of hydrogen at a bright red heat, forms small gray crystalline particles, which under the burnisher become lustrous like iron. Its specific gravity is about 19, and thus nearly approaches that of gold. It is fusible only with difficulty, especially in larger quantities, is brittle, and so hard that it scratches glass. At the ordinary temperature it remains unchanged in the air, but when it is heated in the pulverulent form it burns easily, and produces tungstic anhydride. Hot nitric acid oxidizes it to the same product. Tungsten forms with the other metals extremely hard alloys, the most important of which is ferro-tungsten used in the preparation of tungsten steel.

Molybdenum (Mo; atomic weight 96). This element occurs chiefly in nature as molybdenite, and more rarely as wolframite. In its physical proporties molybdenum far more closely resembles the metals than the non-metals. It is of a silver-white color, with a strong metallic luster, very hard, and melts with extreme difficulty. Its specific gravity is 8.6. Thus far it has found no application in the manufacture of alloys.

Vanadium (V; atomic weight 51.1). Vanadium is quite widely distributed in nature, though only in minute quantities. The best known of the vanadium minerals are *vanadite, descloizite, dechenite* and *volborthite.* Vanadium in small quantities is frequently found in iron ores, especially in pea-ore; it then passes into the iron, and especially into the finery cinders.

The preparation of vanadium by the electric method proposed by Gin, appears to yield the best results. By heating with carbon he reduces vanadic anhydride, V_2O_5 to V_2O_3, moulds the latter with retort-carbon and rosin into the shape of rods, similar to arc-lamp carbons, and uses them as anode, while the cathode consists of steel. The electrodes dip in a bath of iron fluoride and calcium fluoride, so that the fluorine formed on the anode combines with the vanadium to vanadium fluoride, which is converted with the steel cathode to metallic vanadium and iron fluoride.

Vanadium is a brittle, pale gray, metal with a silver-white luster, of a crystalline structure, and is non-magnetic. Its specific gravity is 5.5. It does not oxidize when exposed to the air, even at 212° F., and does not decompose water at 212° F. It fuses at 3236° F. When thrown in the form of powder into a flame it burns, emitting brilliant sparks. The metal is not attacked by hydrochloric and dilute sulphuric acids. It dissolves, with a blue color, in even very dilute nitric acid, as well as in aqua regia.

Notwithstanding its high melting point, vanadium readily alloys with other metals, for instance iron. A mixture of ferric oxide, vanadium pentoxide or vanadic anhydride, V_2O_5, and charcoal yields, when heated in an electric furnace, a crystalline regulus of a bluish-white color, homogeneous fracture and containing 72.96 per cent. iron, 18.16 vanadium and 8.35 carbon. It can be readily drawn out to wire. With copper a bronze-colored, malleable alloy with 96.52 per cent. copper and 3.38 vanadium is in the same manner obtained. It can be readily drawn out to wire, and is harder than copper. With aluminium an alloy is obtained by bringing a mixture of vanadium pentoxide and finely pulverized aluminium into a crucible containing liquid aluminium, and stirring. The malleable alloy contains 2 per cent. vanadium. According to Hélouis, this alloy differs from ordinary aluminium by its ring and might possibly be used for small bells, tuning forks, musi-

cal instruments, etc. When vanadium is melted together with silver two layers are formed, the upper one of vanadium without silver, and the lower one of silver with traces of vanadium.

4. *Tin Group.*

(Tin, Titanium, Zirconium, Thorium).

Of the elements included in this group, only tin and titanium need here be referred to, the others being of no importance for our purpose.

Tin (Sn; atomic weight 117.35). Native tin is of very rare occurence, and then it is combined with lead, and even with gold in Siberia. It can, however, be readily extracted from *tin-stone*, or *cassiterite*, occuring in great abundance in Cornwall, Devonshire, and other localities. A considerable quantity of tin ore is obtained from Saxony, South America, and Australia. The nodular or rounded grains of tin found in beds of streams and in alluvial soil are called *stream-tin*, and are very pure tin-stone: as found in the alluvial soil of the Island of Banca, it is considered the best in the world.

Commercial tin is never pure. The following table shows a set of analyses given by Bruno Kerl: *

	Banca.		British.		Peruvian.		Saxon.	Bohemian.	
	I.	II.	I.	II.	I.	II.		I.	II.
Tin	99.961	99.9	99.96	98.64	93.50	95.66	99.9	99.59	98.18
Iron	0.019	0.2	—	—	0.07	0.07	—	—	—
Lead	0.014	—	—	0.24	2.76	1.93	—	—	—
Copper	0.006	—	0.24	0.16	—	—	—	0.406	1.60
Antimony	—	—	—	—	3.76	2.34	—	—	—
Bismuth	—	—	—	—	—	—	0.1	—	—

Chemically pure tin is a white metal with a strong luster,

* Metallhüttenkunde, 1873.

it has a specific gravity of 7.28 to 7.4, according to the method of preparation, the purest being the lightest. It scarcely oxidizes in moist air, and entirely retains its metallic luster in dry air. It possesses but little tenacity, but is quite malleable, and can be rolled into very thin plates (tin foil). It is highly crystalline, and when bent gives out a crackling noise, the so-called "tin-cry," caused by the crystals rubbing against each other. It possesses a peculiar odor. It melts at 453° F. When fused in contact with air it acquires a film of oxide, and at a white heat burns with a bright flame, and is converted into a whitish powder, known as "putty powder," and used in the arts for polishing.

Unmanufactured tin comes into market as "block tin," as "grain tin," and in small bars or "sticks." Block tin is cast in ingots or blocks in moulds of marble; grain tin is made by heating these ingots until very brittle, and then breaking them upon stone blocks; it is sometimes granulated by melting and pouring into water.

Tin, though soft by itself, possesses a remarkable property of imparting to certain alloys a high degree of hardness. It being quite indifferent towards certain organic acids, it is extensively used for coating other metals, as iron, copper, lead, etc.

Tin alloys readily with lead, antimony, zinc, bismuth, copper, gold, silver, and other metals.

Titanium (Ti; atomic weight 48.1). This comparatively rare element is found in nature as titanic anhydride, TiO_2, in rutile, brookite, anatas; as titanate in combination with oxidized iron as titanic iron. Titanic iron ores of different localities contain from 8 to 50 per cent. of titanic anhydride, and yield pig iron with up to 1.7 per cent. of titanium. Titanium exerts, even in very small quantities, a very energetic influence upon iron, or acts indirectly by the removal of injurious substances, especially sulphur. According to Nau*, pig iron produced from

*Iron, 1892, No. 1004, p. 316.

titaniferous ores, if added to steel, renders the latter free from blisters and, like silicon, counteracts red-shortness.

Metallic titanium is obtained in the following manner: Two copper boats, one containing dry potassium fluotitanate, and the other metallic sodium, are brought into an iron tube which is then filled with pure hydrogen. The boat containing the fluotitanate is first heated to redness, then that containing the sodium, so that the vapor of the metal is carried by the hydrogen over the titanium salt. By this process sodium and potassium fluorides are produced and free titanium. If the two former compounds are afterwards extracted by hot water, the titanium remains behind as a dark gray amorphous powder, resembling iron which has been reduced in hydrogen. The element in this pulverulent form burns brilliantly when heated in oxygen or in the air, forming titanic anhydride. It dissolves easily in hydrochloric acid, hydrogen being evolved.

Moissan obtained metallic titanium in ten to twelve minutes by heating in an electric furnace with a current of 1000 amperes and sixty volts, ten to fifteen ozs. of a compressed and dried mixture of titanic acid and carbon firmly pressed into a coke crucible three inches in diameter. After cooling the crucible showed a mass fused only to a few centimeters deep; fusion was not complete even with a current of 2200 amperes and 60 volts. Beneath the fused titanium was a layer of yellow nitride, and on the bottom of the crucible a layer of blue titanic oxide. The best sample (carbide and oxide) obtained contained 48 per cent. carbon and 2.1 per cent. impurities. By heating the fused mass mixed with titanic acid to the same temperature as before, titanium, free from nitrogen and silicon, with 2 per cent. carbon was formed.

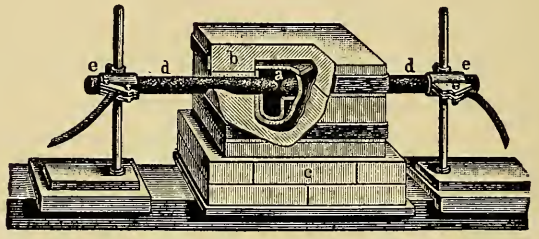
Moissan and Violle's electric furnace in Fig. 1 is arranged as follows:

A cylindrical receptacle of carbon of the same depth and and width is formed from a carbon tube *a* and rests with

its lower end upon a carbon plate. The upper portion carries a carbon plate of the same diameter. The carbon cylinder is contained in a limestone block *b*, being separated from the walls of the latter by a layer of air 5 millimeters thick, and rests upon a support of magnesia *c*. Through two lateral apertures horizontal electrodes (carbon cylinders) *d* are introduced which can be moved at will upon a carriage. The electrodes receive the current by means of thick copper couplings *e* provided with cheeks in which the ends of the electric cable are inserted.

The titanium with 2 per cent. carbon prepared according

Fig. 1.



to Moissan's process in the electric furnace shows a brilliant white fracture and scratches steel and rock crystal. Its specific gravity is 4.87.

Titanium dissolves readily in lead and iron and gives alloys with copper, tin and chromium.

According to Welly, a beautiful golden yellow titanium bronze of excellent durability and ductility is obtained by melting copper with titaniferous iron with the addition of some sulphur, whereby titaniferous copper and a slag containing ferrous sulphide is produced.

The Pittsburgh Reduction Co. produces aluminium-titanium alloys with 0.5 to 10 per cent. titanium.* According to Langley these alloys possess, in addition to

* Engineering and Mining Journal, 1892, Vol. 54, No. 16.

elasticity and great strength, considerable hardness in a rolled or otherwise worked state, while as castings they are not so hard. Even a small quantity of titanium suffices to impart to aluminium greater tensile strength; while that of the latter amounts to 22,300 lbs. per square inch, an aluminium-titanium alloy showed 73,500 lbs. The specific gravity is not much greater than that of pure aluminium. With up to 5 per cent. titanium the alloys show the same shrinkage as aluminium, but are harder, and with 10 per cent. are as elastic as steel. Sometimes the alloys contain in addition 1 per cent. chromium, which renders them still harder and makes them suitable for cutting tools. The alloys are produced by dissolving titanic anhydride in fused aluminium-sodium fluoride, and then adding aluminium.

Rickard* has investigated the behavior of titaniferous aluminium towards the action of hydrochloric, nitric and acetic acids, caustic potash, common salt, and water con-containing carbonic acid.

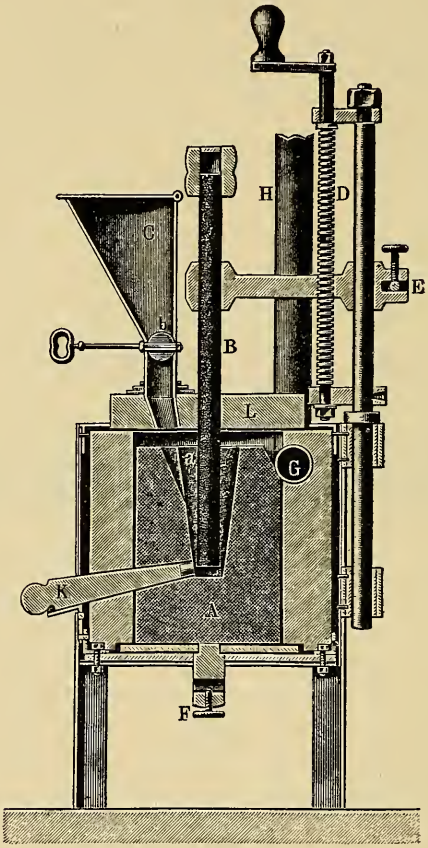
To make a hole in a 1-millimeter thick sheet of an alloy of aluminium with 2 per cent. of titanium, there were required with dilute potash solution, 3 days 20 minutes (pure metal, 7 days 20 hours); with hydrochloric acid, 64 days (pure metal, 46 days 22 hours); with concentrated nitric acid, 14 days 20 hours (pure metal, 28 days 8 hours); with concentrated sea salt solution, 4550 days (pure metal, 6800 days); with strong acetic acid, 1375 days (pure metal, 1810 days). As compared with copper and German silver alloys, the titanium alloy would therefore appear suitable in cases where hydrochloric and acetic acids have to be considered.

In Moissan's electric furnace (see Fig. 1), titanium combines with aluminium and in the Siemens–Martin furnace the alloy can be used to introduce titanium into melted steel, whereby the excess of aluminium is rapidly consumed and scorified.

*The Journal of the Franklin Institute, 1895, No. 1, p. 69.

The electric furnace of the Deutsche Gold und Silber-scheideanstalt of Frankfort-on-the-Main, for continuous working on a large scale, is shown in Fig. 2. It is intended for melting very refractory metals, for the reduction of

Fig. 2.



metallic oxides reducible with difficulty, for the production of carbides, etc. It contains a crucible *a* of carbon *A* with cover *L*, and this forms the negative electrode, to which at *F*, the negative cable is connected. With a crucible of non-conducting material the current is introduced by means

of a conducting carbon rod through a hole in the bottom of the crucible. The binding screw *E* serves for securing the positive cable. By means of an adjusting screw *D*, the positive carbon *B* can be raised or lowered. *C* is the charging funnel with throttle-valve *b*, for the introduction of pulverulent materials, and *K* a stopper for the tap serving for discharging the melted contents of the crucible. The pipes *G* and *H* serve for carrying off evolved gases. The furnace can be used for currents of 100 to 300 ampères, and more.

5. *Lead Group.*

(Lead, thallium.)

Lead (Pb; atomic weight 206.41), This metal is much used in the manufacture of alloys. It is so soft that it may be easily scratched with the finger nail, but it has too little tenacity to be drawn into fine wire, although some lead wire is found in the market. It is very malleable and is extensively used in the forms of sheet-lead and lead-pipe. It was formerly employed for casting statues, but its use for this purpose has been almost entirely abandoned at the present time, experience having shown that, though such statues resist the action of the air quite well, they gradually collapse.

Pure lead is a bluish-white, lustrous, inelastic metal; when freshly cut or melted it shows a bright surface, which, however, rapidly tarnishes on exposure to the air. It is very heavy, its specific gravity being 11.4, and is easily fusible, melting at about 620° F. It boils and volatilizes at a white heat, but cannot be distilled from closed vessels. The affinity of lead for oxygen is so great, that in melting, the surface becomes coated with a yellow layer of oxide; on removing this layer with a hook, the pure white color of the metal shows itself but immediately disappears again. In this manner large quantities of lead can in a short time be converted into oxide. The alloys of lead are distin-

guished by great fusibility, a valuable property for some purposes, and by being, as a rule, much harder than the lead itself.

Lead alloys readily with tin, antimony, bismuth, silver and gold. Its behavior towards iron and zinc has already been referred to (see iron and zinc).

Thallium (Tl; atomic weight 203.64) is a metal very much resembling lead. It is widely distributed, being found in iron and copper pyrites, in blende, in native sulphur, and in lepidolite. It is most profitably extracted from the flue dust of the pyrites burners. It has a strong metallic luster, but quickly tarnishes by oxidation. Its specific gravity is about 11.8, and it is softer even than lead. Several alloys exhibiting characteristic properties have been prepared with the assistance of thallium, but the metal is too expensive to be used for technical purposes.

6. *Silver Group.*

(Silver, mercury and copper.)

The metals belonging to this group are of great importance in the manufacture of alloys, copper being especially distinguished in this respect, since there is an exceedingly large number of alloys used for various industrial purposes of which it forms the principal constituent. The other two metals belonging to this group are also much employed for the same purpose, and it may be said that this group is the one most deserving the attention of all interested in alloys.

Copper (Cu; atomic weight 63.18). This metal has been known from very early times, it being found native in many parts of the earth and requiring, therefore, simply to be melted in order to obtain it in a form suitable for technical purposes. It was used for the manufacture of tools and weapons long before the discovery of methods for the extraction of iron.

Copper has a characteristic yellowish-red (copper-red)

color, but on exposure to the air becomes gradually coated with a brown layer of oxide. Heated to redness in the air it is quickly oxidized, becoming covered with a black scale. It has a specific gravity of 8.9, and is tough, very malleable, and ductile, so that it can be rolled out into very thin leaves and drawn out to fine wires. It melts at a bright-red heat, and seems to be slightly volatile at a strong white heat.

Copper alloys readily with most metals, especially with gold, silver, zinc, tin, nickel, antimony, aluminium, etc., but partially only, or with difficulty, with lead and iron, though of the latter it readily absorbs small quantities. Many of the copper alloys are of great importance. All alloys known as bronze, brass, bell-metal, gun-metal as well as German silver, argentan, etc., contain copper in varying quantities, and possess properties which render them indispensable for certain branches of the metal industry.

Mercury (Hg; atomic weight 199.88). This remarkable metal, sometimes called *quicksilver*, has also been known from remote times, and, perhaps more than all others, has excited the attention and curiosity of experimenters by reason of its peculiar physical properties. Metallic mercury is occasionally found free, and in union with silver and gold, but its chief source is the sulphide or *cinnabar*. Mercury has a nearly silver-white color and a very high degree of luster. It is liquid at ordinary temperatures and solidifies only when cooled to —40° F. In this state it is soft and malleable. The specific gravity of pure mercury is 13.596. It boils at 662° F., but volatilizes to a sensible extent at all temperatures. In regard to its behavior in the air, it is a medium between the metals, readily combining with oxygen and those which show no special affinity for it. Since it does not combine with oxygen at an ordinary temperature, and retains its metallic luster even in a moist atmosphere, it is generally included among the so-called noble metals.

But when it is heated for some time to near its boiling

point, it slowly absorbs oxygen and is gradually converted into a bright-red, crystalline powder—mercuric oxide. By heating the oxide thus formed somewhat more strongly, it is again decomposed into its constituents, oxygen and metallic mercury.

Mercury alloys or, as it is generally termed, *amalgamates* directly with many metals, with some, for instance, iron only indirectly, and not at all with platinum. The amalgams are either liquid, the degree of fluidity depending on the quantity of metals compounded with the mercury, or they form solid bodies with perceptible crystallization and sometimes a high degree of hardness. Several of these amalgams are employed for technical purposes.

Silver (Ag; atomic weight 107.06). This element is frequently found in the metallic or native state crystallized in cubes or octahedra, which are sometimes aggregated together. It is more frequently met with, however, in combination with sulphur, forming the sulphide of silver, which is generally associated with large quantities of the sulphides of lead, antimony, and iron. The metal has been known from very early times, and although quite widely diffused is found in comparatively small quantity, and hence bears a high value, which adapts it for a medium of currency. It has a characteristic (silver-white) color, which it retains even when fused in contact with air, and by reason of this property has to be classed with the noble metals. Its specific gravity is about 10.48 and may be increased by hammering. It is harder than gold, but somewhat softer than copper, and next to gold is the most ductile of all metals. It can be rolled out into thin leaves, so that a small quantity of silver suffices to cover a large surface, and on account of its toughness can be drawn out into wires so fine as to be scarcely perceptible by the naked eye. It melts at about 1680° F.; at a white heat a strong volatilization takes place, whereby the silver is converted into bluish-purple vapor. The behavior of silver when

fused in contact with the air is very remarkable. It absorbs a considerable quantity of oxygen without, however, chemically combining with it, the oxygen being again expelled as the metal solidifies.

Silver is too soft to be worked by itself, pure silver being only used for special purposes where the presence of another metal would exert an injurious effect. For all other purposes alloys of silver, especially such as contain a certain quantity of copper, are employed; silver coins and silver utensils consisting, for instance, of an alloy of silver and copper.

Silver alloys readily with most metals, but does not alloy with iron.

7. *Gold Group.*

(Gold and Platinum.)

The metals belonging to this group are distinguished by a high specific gravity, and are the densest bodies known. Their chief characteristic is, however, their slight affinity for oxygen. They can be melted in contact with the air and exposed to the highest temperatures without combining with oxygen. Even their combinations with oxygen, which can be obtained in an indirect manner, are so unstable that on slight heating they yield up the oxygen and are decomposed, the pure metal being left behind. On account of being found in comparatively small quantities, they bear a high value and are the most precious of all metals.

Gold (Au; atomic weight 196.2). Gold has been known from the earliest times, and its comparative rarity, its exceptional color, and its power of resisting atmospheric influences have caused it to be esteemed as one of the most precious metals. As might be expected from its want of direct attraction for oxygen, gold is one of those few metals which are always found in the metallic state; and it is remarkable as being one of the most widely distributed

elements, although seldom met with in large quantity in any one locality. Gold has a beautiful yellow color, a strong metallic luster unalterable in the air, a specific gravity of 19.5, is the most ductile of all metals, and can be drawn out into extremely fine wire. It surpasses all other metals in malleability, and can be beaten out into thin leaves which transmit the light with a green color. It has a very high melting point (about 2372° F.) and becomes fluid only at a white heat. It can readily be volatilized at a high temperature produced by means of electricity.

Pure gold is nearly as soft as lead, so that articles manufactured from it would speedily wear out. In order to increase its hardness when used for articles of jewelry or coinage, it is alloyed with silver or copper or with both. It also alloys readily with most other metals.

Platinum (Pt; atomic weight 194.31). This metal is always found in the metallic state in the form of grains and irregular pieces. As a rule it is, however, not pure, but the grains or pieces are generally associated with a group of other metals possessing similar properties, viz., rhodium, palladium, iridium, ruthenium, as well as gold, silver and iron. Platinum has a gray-white color, resembling that of some brands of steel. It is heavier than gold, its specific gravity being 21.5. Up to the commencement of the present century platinum was considered infusible, but at the present time a quantity of platinum up to 450 pounds can be readily fused with the assistance of a heat produced by the use of an oxyhydrogen blowpipe. Platinum is distinguished by great chemical indifference, it being scarcely acted upon by any single acid, but like gold only dissolves in a mixture of nitric acid and hydrochloric acid (nitromuriatic acid). On account of this indifference and its comparatively great hardness, it is especially used in the manufacture of chemical utensils, it being in this respect equal to gold.

In a certain respect platinum has some similarity with

iron. It can be welded and readily combines with carbon to a mass with a lower melting point than that of pure platinum. Platinum forms alloys readily and in any desired proportions with most metals.

8. *Bismuth Group.*

(Bismuth, Antimony.)

Bismuth (Bi; atomic weight 207.5). This element is only sparsely distributed in nature, and nearly always occurs in the free state, though it is sometimes found associated with sulphur, copper and lead. It is grayish-white with a reddish tinge; is brittle, and can therefore be readily powdered, and crystallizes very easily, Its specific gravity is 9.8; it melts at 507° F.; it shares with water the property of expanding considerably on passing from the liquid to the cold state.

Bismuth being too brittle to be used by itself, its chief employment is in the preparation of certain alloys with other metals. Some kinds of type metal and stereotype metal contain bismuth whereby they acquire the property of expanding in the mould during solidification and are forced into the finest lines of the impression. Bismuth is also remarkable for its tendency to lower the fusing points of alloys which cannot be accounted for by its own low melting point. Bismuth is also employed together with antimony in the construction of thermo-electro piles.

Antimony (Sb; atomic weight 119.6). This element very seldom occurs free in nature, but is usually found combined with sulphur. The commonest form is the trisulphide (Sb_2S_3)—the mineral called gray antimony ore or antimonite.

In its physical properties antimony so closely resembles the metals that it is frequently included in this group of elements. Its chemical properties and the compounds which it forms show, however, that it is much more closely allied to the nitrogen group of the non-metals. It is a lustrous

crystalline solid of a bluish-white color, with a specific gravity of 6.72. It melts at 824° F. and crystallizes on cooling in rhombohedra. When slowly cooled its fracture shows large crystalline laminæ, but when quickly cooled the fracture is granular. It is volatilized at a bright red heat, and at a white heat may be distilled in a stream of hydrogen gas. It is brittle and can be converted into a fine powder by pounding in a mortar and, like bismuth, cannot be used by itself. It is, however, of importance for the manufacture of several useful alloys, and possesses the property of increasing the hardness of a metal even if mixed with it only in small quantities.

Arsenic (As; atomic weight 74.9). This element, like antimony, is frequently classed among the metals, it having strongly marked metallic characteristics such as metallic luster and conductivity for electricity. The chemical character and composition of its compounds connects it in the closest manner with phosphorus.

Arsenic occurs in nature both native and in chemical combination with other elements. Native arsenic is sometimes found in the crystalline state, but it generally occurs in rough lumps which readily break up into uneven laminæ. More common in nature are its compounds, of which the most important are: Arsenical iron, arsenical iron pyrites or mispickel, smaltine or tin-white cobalt, realgar and orpiment. Besides these, arsenic is also found in combination with oxygen as white arsenic, and in the form of arsenic acid in various minerals. The only important mine of arsenic-bearing ores, thus far known in this country, is located at Brinton, Virginia. It was opened in 1903, and by its discovery American manufacturers have been relieved of the necessity of depending upon foreign sources of supply of an article indispensable in the arts and industries.

Arsenic when freshly broken possesses a steel-gray color and strong metallic luster. It is very brittle and may therefore be easily reduced to powder. Its specific gravity is

5.7. When exposed to moist air arsenic loses its metallic luster and becomes dull in consequence of surface oxidation. When heated in the air it volatilizes and burns, forming white fumes of arsenious anhydride. At the same time an unpleasant garlic-like odor is noticed. Arsenic is used for hardening lead in the manufacture of shot, and some other alloys. However, on account of its extremely poisonous nature its use must be avoided in alloys to be employed for the manufacture of utensils in which food is to be preserved.

An alloy, as generally understood, is a combination of two or more metals, but there are some so-called alloys consisting of but one metal, whose properties have been changed in a remarkable manner by the addition of a non-metallic element. It has been previously pointed out that the properties of iron are sensibly changed by a very small addition of sulphur or phosphorus, and that carbon acts in a similar manner. It will, therefore, be necessary to briefly describe these elements.

Sulphur (S; atomic weight 31.96). This element is remarkable for its abundant occurrence in nature in the uncombined state. It is purified by distillation, and then forms a crystalline mass of a characteristic pale yellow color, which melts at 232° F., and at about 780° F. is converted into ruby-colored vapors. By the admixture of organic substances sulphur acquires a black color in melting. The affinity of sulphur for most metals is so great that they combine with it with great energy. If, for instance, copper be thrown into a vessel containing sulphur heated to the boiling point, the combination takes place and is attended with vivid combustion. An intimate mixture of iron and sulphur needs only to be slightly heated to effect the union of both bodies, which is accompanied by vivid glowing. The combination can even be introduced by moistening a large quantity of the mixture with water.

The combinations of the metals with sulphur are in most

cases distinguished by a high degree of brittleness, a small admixture of sulphur being generally sufficient to impart to them this property. And this property being by no means a desirable one, care should be had in making experiments in the preparation of alloys to use only metals absolutely free from sulphur. It may also be remarked that in such experiments the presence of every foreign body exerts a disturbing influence, and, in order to obtain satisfactory results, it is recommended to use only chemically pure metals.

Carbon (C; atomic weight 11.97). Carbon is the most widely diffused element, it forming a never-wanting constituent of all animal and vegetable bodies. Few elements are capable of assuming so many different aspects as carbon. It is met with transparent and colorless in the diamond, opaque and black and quasi-metallic in graphite or black lead, velvety and porous in wood charcoal and, under new conditions, in anthracite, coke and gas-carbon.

In nature carbon appears crystallized in the hexagonal form as graphite, in the tessular form as diamond, and amorphous as coal in the ordinary sense of the word.

For our purposes only the modifications known as graphite or plumbago and as amorphous coal are of interest.

Carbon, for which no actual solvent is known, has the remarkable property of dissolving in considerable quantities in several melted metals, the best known example of this being its behavior towards iron.

As is well known, in the manufacture of iron pure iron is never obtained, but the so-called cast-iron, which contains a certain quantity of carbon. There can be no doubt that the carbon is actually dissolved in the iron, for in cooling certain varieties of cast-iron containing much carbon a certain quantity of it is separated out in a crystalline form as graphite.

The content of carbon, as previously stated in speaking of iron, exerts a considerable influence upon the qualities

of a metal, the special properties of the various kinds of iron known as wrought-iron, steel, and cast-iron being chiefly due to the varying quantity of carbon they contain. Generally speaking, it may be said a content of carbon makes the metal more fusible, but it is impossible to state in a general way what other influence is exerted upon its properties, this influence depending essentially on the quantity admixed. It is, therefore, only possible to determine in each case the influence exerted upon the properties of a metal by the presence of carbon.

Phosphorus (P; atomic weight 31). This element is never known to occur uncombined in nature, and its properties render the use of special precautions necessary for its management, it being very inflammable. A stick of phosphorus held in the air always appears to emit a whitish smoke, which in the dark is luminous, this effect being chiefly due to a slow combustion the phosphorus undergoes by the oxygen of the air. Larger quantities of phosphorus exposed to the air become so thoroughly heated by oxidation as to commence to melt and spontaneously ignite. A content of phosphorus in metals is only possible if ores containing phosphoric acid are used in their preparation, whereby a reduction of the phosphoric acid to phosphorus takes place, which combines with the metal.

In speaking of iron it has already been pointed out that a small content of phosphorus renders it red-short or hot-short, *i. e.*, it makes it so brittle that it cannot be worked under the hammer even at red heat. If metals be intentionally mixed with phosphorus, the mixtures—they cannot be called alloys in the strict sense of the word—show also a high degree of brittleness, though it is not so far-reaching as is the case with iron, and the metal acquires certain properties making it especially suitable for many purposes. The so-called phosphor-bronze consists of a mass which besides copper contains a very small quantity of phosphorus, and shows properties rendering it especially desirable for some uses.

CHAPTER IV.

GENERAL PROPERTIES OF ALLOYS.

From what has been said in the preceding chapters, it will be understood that the properties of the different metals vary very much and that but few possess properties in common. It will next be necessary to consider the changes which certain metals undergo by melting together or alloying.

1. *Liquation.* When a solution fluid at the ordinary temperature is allowed to cool below its congealing point, the process frequently takes place in such a manner that as cooling progresses certain constituents of the solution congeal first, while the solution still remaining liquid undergoes constant changes as regards its composition until the latter remains constant, when this solution also congeals. The solution congealing last is called the *eutectic* (most fluid) solution. However, on examining the congealed eutectic solution more closely it will be found that during cooling a disintegration of the constituents previously dissolved one in another has taken place, and that the solution now forms only an intimate mixture of these constituents. When the temperature is raised the mixture again combines to the eutectic solution which with a further increase in the temperature redissolves the previously crystallized bodies.

If, for instance, a common salt solution (sodium chloride solution) with 3.8 per cent. common salt be allowed to cool, there is formed at—3.25° C. (26.5° F.) ice free from common salt, and the solution becomes richer in common salt. The formation of ice at this temperature continues till the solution contains 5.5 per cent. of common salt. If,

however, the temperature becomes lower, formation of ice again takes place and the solution becomes richer until at a temperature of —22° C. (—7.6° F.) the eutectic solution with 23.5 per cent. of common salt remains behind, when ice is no longer separated and the whole congeals, disintegrating, however, into an intimate mixture of common salt and ice. The entire congealed mass consists therefore of the previously formed ice crystals mixed with the finally congealed eutectic solution. If, however, a common salt solution containing more than 23.5 per cent. common salt be subjected to cooling, the common salt crystallizes and the solution becomes poorer until at —22° C. (—7.6° F.) it has again acquired the composition of the eutectic solution and freezes as such. In this case the congealed mass consists therefore of the eutectic solution with imbedded common salt crystals.

Many alloys show a similar behavior in cooling. The proof of this is furnished by the metallographic examination, *i. e.*, by grinding the fracture of an alloy, polishing it and also treating it by chemical agents, or by oxidizing it by heating whereby the constituents assume different colors. The surface thus treated is then examined under the microscope.

If, for instance, a melted silver-copper alloy* containing more than 72 per cent. of silver be allowed to cool, silver crystals are first separated, while an alloy poorer in silver still remains liquid. This separation of silver is continued until the content of silver has been reduced to 72 per cent., which takes place when the temperature has fallen to 1404° F. This is the eutectic point, and the eutectic alloy which now, previous to congelation, no longer separates any constituents but solidifies throughout at that temperature, consists, therefore, of 72 parts silver and 22 parts copper. In congealing it disintegrates, however, to an

* Melting point of pure silver = 1760° F.; of pure copper = 1983.2° F.

intimate mixture of its constituents, which on reheating first dissolve again one in another, and with an increase in the temperature gradually dissolve the previously separated silver. By heating the ground surface of such an alloy rich in silver, the copper oxidizes and can under the microscope be plainly distinguished from the non-oxidized silver. Fig. 3 shows, 480 times magnified, the ground surface of an alloy with 85 per cent. silver and 15 per cent. copper, which has thus been treated. The lighter portions,

Fig. 3.

a, are nearly pure silver; the black portions, *b*, are the eutectic mixture consisting of 72 parts silver and 28 parts copper.

If, on the other hand, the alloy contains less than 72 per cent. silver and more than 28 per cent. copper, copper is, in congealing, first separated till at 1404° F., the composition of the eutectic alloy has again been reached and the latter also congeals. Fig. 4 shows, 480 times magnified, the appearance of an alloy with 35 per cent. silver, which has been treated in the manner previously described. The

black portions, *c*, are the copper first separated; *b* is the eutectic mixture of silver and copper which has been formed.

FIG. 4.

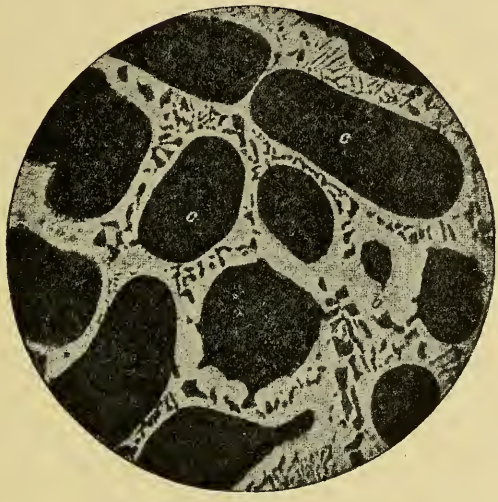


FIG. 5.

Fig. 5 shows, 480 times magnified, the eutectic alloy

with 72 parts silver and 28 parts copper; it contains copper and silver as an intimate mixture.

The alloys of lead and tin, the eutectic alloy of which contains 31 per cent. lead and 69 per cent. tin and congeals at 356° F., behave in a similar manner; also the alloys of lead and antimony, the eutectic alloy of which consists of 87 per cent. lead and 13 per cent. antimony and congeals at 477° F., as well as numerous other alloys. Alloys containing three or more constituents also congeal, as a rule, not uniformly, and single constituents are first separated until the eutectic alloy which congeals last of all remains behind. It is, however, more difficult to recognize the processes taking place thereby than with alloys of two constituents.

It may also happen that instead of the separate metal a definite chemical combination crystallizes from the congealing alloy, as for instance, according to Le Chetalier, the compound $SbCu_2$ from copper-antimony alloys.

This disintegration of an alloy homogeneous in a liquid state is called *liquation*. In metallurgical processes it is occasionally made use of for the purpose of separating a metal or an alloy richer in noble metal, from another metal or alloy (Pattinson's process for extracting silver from lead). However, in *working* metals liquation is always troublesome, and should be avoided as much as possible. Since the physical properties of an alloy—strength, ductility, hardness, color, etc.—are closely related to its average composition, and as a slight change in the latter frequently produces not inconsiderable variations, the properties of a piece of metal solidified with liquation will not only be different and less suitable for the intended purpose than would be the case with uniform solidification, but in various parts of the same article variations will show themselves, which may injure its usefulness or render it entirely useless. Generally speaking liquation shows itself the plainer and the variation in the composition of the

alloy becomes the greater, the slower the process of cooling the fused alloys is effected. Hence, rapid cooling of an alloy while solidifying is an effective means of preventing liquation, or to limit it to a slighter degree.

From this it will be seen that the properties of one and the same alloy may be changed by remelting and renewed cooling, if in one case liquation is more promoted or rendered more difficult than in another; and further that liquation will appear to a greater extent the thicker the cross sections of a casting are.

Since in the solidification of liquid metals and alloys cooling progresses from the exterior towards the center, advancing more rapidly here and more slowly there, a concentration of more refractory alloys usually takes place on the outside and one of more fusible alloys in the center; but generally liquation is more perceptible in the center of a casting than on the outside. However, since many bodies expand, hence, decrease their specific gravity, at the moment of solidification, and therefore float upon the non-solidified surface (ice upon water, solid cast-iron upon fused), it will be understood that when liquation takes place, not only the exterior surfaces of the solidified piece of metal show a concentration of the more refractory alloy, but also the upper cross sections; while in other cases where this behavior does not take place, where, briefly, the alloy solidifying first is specifically heavier than that remaining fluid, it accumulates on the bottom of the piece of metal. Hence variations in the composition of the upper and lower cross-sections prove by no means, as has frequently been supposed, that a separation of alloys of different composition has taken place while in a fluid state, but only that the alloy first separated in consequence of liquation possessed at that temperature a different specific gravity from the non-solidified more readily fusible alloy; and from this it may be further inferred that in a cooled state the specific gravities of the separated alloys stand in

the same relation to each other as at the moment of liquation, or in other words that, after cooling, the uppermost alloy is also specifically the lightest.

However, the property of liquation does not show itself to the same extent in all alloys. In some it is so strong that it cannot be avoided even with as rapid cooling as possible, while others scarcely show a trace of it even with quite slow cooling.

Most *copper-tin alloys* show a very distinct tendency towards liquation, which generally increases with the content of tin. From alloys richer in copper, crystals richer in tin separate in the slower cooling portions of the casting, which may be plainly distinguished from the actual alloy by their lighter color, and are called *tin-stains*. In alloys containing more than 50 per cent. tin, the upper cross-sections are, according to Riche, richer in tin, and the lower richer in copper; in alloys poorer in tin no difference, however, is perceptible in the lower and upper cross-sections.

The tendency of copper-tin alloys towards liquation is claimed to be overcome by the addition of small quantities of zinc. French pieces of ordnance examined by Riche contained

	Cu	Sn	Zn	Pb
In the interior.....	89.44	8.91	1.39	0.16
In the circumference	89.04	9.51	1.30	0.16

while in the tin-stains accumulated around the axes of the pieces of ordnance, the content of tin amounted to 12.3 to 14.5 per cent. At any rate liquation was not considerable; and, what is remarkable, the average composition shows a concentration of the content of tin towards the circumference.*

*However, this proves by no means that the composition of the exterior parts, as found, accurately represents the composition of the alloy when originally solidifying. After solidification the crust formed on the circumference contracts, and thereby exerts a powerful pressure upon the more readily fusible alloys—in this case richer in tin—enclosed in the center,

Copper-zinc alloys possess very little or no tendency towards liquation, and in this respect are favorably distinguished from the copper-tin alloys.

Copper-lead alloys show strong tendency towards liquation. From cupriferous lead, the lead may, by careful heating, be melted out, the copper remaining behind in the form of so-called copper-thorns.

Silver-copper alloys, as previously explained, show strong tendency towards liquation, a fact which is of considerable importance as regards the use of such alloys for coins, and renders the preparation of blanks of uniform composition more difficult. As previously pointed out the eutectic silver-copper alloy consists of 72 parts silver and 28 parts copper. In alloys with more than 72 per cent. silver, the content of the latter increases towards the center of the casting, while in alloys poorer in silver the content of copper increases in that direction. In an alloy with 69.5 per cent. silver, the upper cross-sections are, as a rule, richer in copper, and the lower richer in silver.

Gold-copper alloys with from 23.7 to 92.5 per cent. gold, show, according to Levol, scarcely any sign of liquation after actual alloying of the two metals has taken place; however, to effect this, especially with alloys richer in gold, several remeltings and frequent stirring are required.

Gold-silver alloys show no tendency towards liquation after actual alloying has taken place.

Lead-silver alloys possess strong tendency towards liquation, as shown by the use made of this behavior in the Pattinson process. Levol found the content of silver considerably greater in the center of the cast and solidified alloys.

Zinc-tin alloys also show considerable liquation, especially when the content of zinc predominates.

whereby they are forced into the pores of the solidified crust. In some alloys richer in tin (bell bronzes) these alloys solidifying last, and forced through the pores of the crust, frequently appear in the form of globules on the exterior surface of the casting and sometimes form masses of excrescences.

2. *Specific Gravity.* The specific gravity or density of alloys corresponds only in a few cases with that which would result by calculation from the specific gravities of the constituents, *i. e.*, with the specific gravity which a purely mechanical mixture of the constituents would possess. In some cases the specific gravity is lower than that calculated, expansion having taken place in alloying. More frequently it is higher than that found by calculation, condensation having taken place. Sometimes an alloy possesses a higher specific gravity than that of its separate constituents.

Expansion, *i. e.* decrease in the specific gravity, has been observed in copper-silver alloys, and lead-silver alloys with less than 30 per cent. silver; in tin-antimony alloys and lead-antimony alloys. Condensation has been found in alloys of copper with tin; copper with zinc with a content of zinc between 35 and 80 per cent.; lead with gold; tin with silver, etc. As an example of a particularly strong condensation may serve the copper-tin alloy with 38 per cent. tin; its specific gravity being 8.91, while that of copper was found to be only 8.89 and that of tin 7.31.

Many comprehensive investigations regarding the specific gravities of alloys have been made. However, the results of such investigations must be accepted with caution, because, as is well known, the specific gravity of every metal varies between wide limits, and is dependent upon the manner of its previous working and treatment. Hence for every experiment not only the specific gravity of each separate metal used has to be accurately determined, but care must also be taken to avoid as much as possible all sources of error, which may readily arise from the presence of gas bubbles or small hollow spaces in castings, by either converting the metals into a fine powder, or by getting rid of the hollow spaces by mechanical means previous to determining the specific gravity. With alloys it has further to be taken into consideration that in consequence of liqua-

tion the specific gravity varies in different places of the casting. Some investigators have committed an error in finding the calculated specific gravity by assuming it to be the arithmetical mean between the numbers denoting the two specific gravities, or, in other words multiplying the percentage weight of each constituent by its specific gravity, adding the results and dividing by 100. The specific gravity should be calculated from the volumes, and not from the weights. Dr. Ure* gives the correct rule as follows: Multiply the sum of the weights into the products of the two specific gravity numbers for a numerator, and multiply each specific gravity number into the weight of the other body, and add the products for a denominator. The quotient obtained by dividing the said numerator by the denominator is the truly computed mean specific gravity of the alloy. Expressed in algebraic language, the above rule is

$$M = \frac{(W + w)Pp}{Pw + pW},$$

where M is the mean specific gravity of the alloy, W and w the weights, and P and p the specific gravities of the constituent metals.†

Of the determinations of the specific gravities of alloys the following have been selected as the most reliable.

The determinations of the specific gravities of *copper-tin alloys* made by Riche and Thurston‡ are given in the annexed table. Riche determined the specific gravity with the assistance of metallic shavings which, to expel air enclosed between them, were boiled in the flask serving for the determination of the specific gravity. Thurston used

*Ure's Dictionary. Vol. 1, p. 49.

†Report on a Preliminary Investigation of the Copper-tin Alloys. Washington, 1879.

‡Report on a Preliminary Investigation of the Copper-tin Alloys. Washington, 1879.

small pieces as free from flaws as possible, and weighing from 1¾ to 2½ ounces each. These pieces were cut from a bar previously used for determining the strength. To cleanse them they were first washed in alcohol, dried, boiled two or three hours in water to expel the air enclosed in the pores, and, after allowing them to cool in the vessel used for boiling, were brought under the receiver of an air-pump to completely remove any particles of air remaining, and then quickly into a beaker filled with distilled water, in which they were weighed, being suspended by means of a very fine platinum loop to the beam of the balance.

The numerical values found for the same alloys show, to be sure, quite considerable variations; but comparing the results obtained as a whole, they agree in many important points. Both series show that when small quantities of tin are added to copper, the alloy, as might be expected on account of the smaller specific gravity of tin, becomes specifically lighter than copper, but as soon as the content of tin exceeds 10 per cent. the decrease in the specific gravity becomes less with an increasing content of tin than it should be according to calculation, *i. e.*, with an increasing content of tin the alloys show an increasing condensation (contraction). From an alloy with 20 per cent. onward, this condensation increases to such an extent that the specific gravity of the alloys increases instead of decreases with the increasing content of tin, until, according to both series, it reaches the maximum in the alloy with 38.3 per cent. tin ($SnCu_3$) and then gradually approaches again the specific gravity according to calculation. According to Thurston's series the condensation is so considerable that alloys with 22.5 to 38.29 per cent. tin are specifically heavier than pure copper, while, according to Riche, the specific gravity of one alloy only ($SnCu_3$) exceeds that of copper. Alloys with less than 10 per cent. tin show, according to Thurston, slight expansion, as well as, according to Riche, alloys with less than 16 per cent. copper.

Composition of the alloys examined.			Specific Gravities.							
			According to Riche.				According to Thurston.			
					Difference.				Difference.	
Copper.	Tin.	Atomic Formula.	Found.	Calculated.	Expansion.	Contraction.	Found.	Calculated.	Expansion.	Contraction.
100·00	—	Cu	8.89	—	—	—				
98.10	1.90	$SnCu_{98}$	—	—	—	—	8.791	—	—	—
97.50	2.50	—	—	—	—	—	8.564	—	—	—
96.27	3.73	$SnCu_{48}$	—	—	—	—	8.511	—	—	—
92.80	7.20	$SnCu_{34}$	—	—	—	—	8.649	8 712	0.063	—
92.59	7·50	—	—	—	—	—	8.694	—	—	—
90.00	10.00	—	—	—	—	—	8.684	—	—	—
89.00	11.00	$SnCu_{16}$	8.84	8.69	—	0.15	8.669	8.614	—	0.055
87·50	12.50	—	—	—	—	—	—	—	—	—
86·57	13.43	$SnCu_{12}$	—	—	—	—	8.648	—	—	—
84.33	15.67	$SnCu_{10}$	8.87	8.60	—	0.27	8.681	8.534	—	0.147
82.50	17.50	—	—	—	—	—	—	—	—	—
81.15	18.85	$SnCu_8$	8.84	8.54	—	0.30	8.792	—	—	—
80.00	20.00	—	—	—	—	—	—	—	—	—
79.02	20.98	$SnCu_7$	8.72	8.50	—	0.22	8.740	8.444	—	0.296
77·50	22.50	—	—	—	—	—	—	—	—	—
76.32	23.68	$SnCu_6$	8.72	8.46	—	0.26	8.917	—	—	—
72·91	27.09	$SnCu_5$	8.62	8.40	—	0.22	8.565(?)	—	—	—
72.50	27.50	—	—	—	—	—	—	—	—	—
70.00	30.00	—	—	—	—	—	8.925	8.318	—	0.607
68.25	31.75	$SnCu_4$	8.75	8.32	—	0.43	8.932	—	—	—
67·50	32.50	—	—	—	—	—	8.938	8.250	—	0.688
65.00	35.00	—	—	—	—	—	8.907	—	—	—
62.50	37.50	—	—	—	—	—	8.947	—	—	—
61·71	38.29	$SnCu_3$	8.91	8.21	—	0.70	8.956	—	—	—
57·50	42.59	—	—	—	—	—	8.970	8·150	—	0.820
56.32	43.68	Sn_6Cu_{12}	—	—	—	—	8.781	—	—	—
52.50	47.50	—	—	—	—	—	8 682	—	—	—
51.80	48.20	$SnCu_2$	8.15	8.04	—	0.11	8.643	—	—	—
47.95	52.05	Sn_7Cu_{12}	—	—	—	—	8.560	7·999	—	0.561
47·50	52.50	—	—	—	—	—	8.442	—	—	—
44.63	55.37	Sn_2Cu_3	8·06	7·93	—	0.13	8.446	—	—	—
42.50	57.50	—	—	—	—	—	8.312	7·893	—	0·419
41.74	58.26	Sn_3Cu_4	—	—	—	—	8.437	—	—	—
39.20	60.86	Sn_5Cu_6	—	—	—	—	8.302	—	—	—
37.50	62.50	—	—	—	—	—	8.182	—	—	—
34.95	65.05	SnCu	7.90	7.79	—	0.11	8.101	—	—	—
28.72	71.28	Sn_4Cu_3	—	—	—	—	8.013	7·755	—	0·258
27·50	72.50	—	—	—	—	—	7.948	—	—	—
24.38	75.62	Sn_5Cu_3	—	—	—	—	7.915	—	—	—
22.50	77.50	—	—	—	—	—	7.835	—	—	—
21.18	78.82	Sn_2Cu	7.59	7.58	—	0.01	7.774	—	—	—
17·50	82.50	—	—	—	—	—	7 770	7·566	—	0·214
15.19	84.81	Sn_3Cu	7.44	7.50	0.06	—	7.690	—	—	—
12.50	87.50	—	—	—	—	—	7.657	7·487	—	0·170
11.84	88.16	Sn_4Cu	7.31	7.46	0.15	—	7.543	—	—	—
9.70	90.30	Sn_5Cu	7.28	7.43	0.15	—	7.552	7·443	—	0·109
7.50	92.50	—	—	—	—	—	7.487	7·415	—	0·072
4.29	95.71	$Sn_{12}Cu$	—	—	—	—	7·417	—	—	—
2.50	97.50	—	—	—	—	—	7.360	7·346	—	0·014
1.11	98.89	$Sn_{48}Cu$	—	—	—	—	7.342	—	—	—
0.55	99.43	$Sn_{96}Cu$	—	—	—	—	7.305	—	—	—
—	100.00	Sn	7.31	—	—	—	7.299	—	—	—
							7.293	—	—	—

By heating to a red heat copper-tin alloys with a certain content of tin and tempering in water, and *vice versa* by

reheating and subsequent slow cooling, the specific gravity is changed in a remarkable manner. From a series of experiments made in this direction, Riche obtained the following results:

Alloys with 20.80 per cent. tin.

	Specific gravities.									
	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.
Cast	8.787	8.858	8.825	8.862	8.863	8.780	8.715	8.822	8.842	—
Tempered	8.823	8.915	8.863	8.896	8.906	—	—	—	—	8.747
Annealed	8.817	8.907	8.847	8.886	8.894	8.808	8.739	8.844	3.863	—
Tempered	8.849	8.927	8.874	8.907	8.922	—	—	—	—	8.871

Alloys with 18 per cent. tin.

	Specific gravities.	
	I.	II
Cast	8.737	8.873
Annealed	8.733	8.863
Tempered	8.763	8.911
Annealed	8.753	8.889
Tempered	8.775	8.926
Tempered	8.786	8.927

Alloys with 20 per cent. tin.

From a cast block weighing 4 lbs. four bars each weighing about 4¾ ounces were cut and used for the experiments.

	Specific gravities.			Specific gravities.	
	I.	II.		III.	IV.
Tempered	8.704	8.719	Annealed	8.752	8.686
Annealed	8.712	8.728	Tempered	8.780	8.713
Tempered	8.730	8.747	Annealed	8.777	8.714
Annealed	8.724	8.744	Tempered	8.804	8.736
Tempered	8.756	8.763	Annealed	8.815	8.750
Annealed	8.741	8.759	Tempered	8.841	8.774
Again annealed	8.751	8.769	Again tempered	8.850	8.787
Tempered	8.775	8.792	Annealed	8.807	8.760

These experiments show that the specific gravity of copper-tin alloys with 18 to 21 per cent. tin is progressively increased by repeated tempering, while annealing has a

contrary, but less powerful effect, *i. e.* the decrease in the specific gravity produced by annealing is unable to equalize the increase by tempering, so that by alternate tempering and annealing a constant average increase in the density remains perceptible. The limit above which a repetition of annealing produces no effect has not been determined.

The increase in the specific gravities of the above-mentioned alloys by tempering may probably be closely related to liquation decreased by rapid cooling, and the decrease by annealing to liquation promoted by slow cooling.

Alloys poorer in tin, in which liquation, as a rule, is less perceptible, show, however, a different behavior. By repeated tempering and annealing, Riche found the following specific gravities:

Alloys with 12 per cent. tin.

	Specific gravities.
Tempered	8.625
Annealed	8.632
Tempered	8.624
Annealed	8.635
Tempered	8.632

Alloys with 10 per cent. tin.

	Specific gravities.			
	I.	II.	III.	IV.
Cast	8.564	8.677	8.684	8.491
Tempered	8.516	8.635	8.657	8.428
Annealed	8.528	8.643	8.670	8.431
Tempered	8.532	8.645	8.671	8.437
Annealed	8.536	8.648	8.674	8.434
Tempered	8.529	8.648	8.673	8.436
Annealed	8.526	8.643	8.676	8.436
Tempered	8.526	8.626	8.664	8.436

Further the same alloy:

	Specific gravities.	
	V.	VI.
Cast	8.541	8.705
Annealed	8.491	8.689
Tempered	8.495	8.684
Annealed	8.504	8.692
Tempered	8.505	8.693
Annealed	8.479	8.651
Tempered	—	8.661

Alloys with 6 per cent. tin.

Specific gravities. I.		Specific gravities. II.	III.
Cast	8.537	Cast	8.519	—
Tempered	8.491	Annealed	8.492	8.807
Annealed	8.501	Tempered	8.491	8.806
Tempered	8.502	Annealed	8.496	8.802
Annealed	8.507	Tempered	8.495	8.804
Tempered	8.505	Annealed	8.496	8.809

A glance at the above tables shows that, as in alloys richer in tin, an increase in the specific gravity cannot be obtained by repeated tempering and annealing, but that rather a decrease takes place, and that in some cases the effect of one tempering results in a decrease of density, and of annealing in an increase; further, that the poorer the alloy is in tin the sooner the limit is reached at which further treatment of the alloy produces no change in the specific gravity.

By mechanical working—hammering, pressing, rolling—the specific gravity of copper-tin alloys is increased.

Copper-zinc alloys. By experiments executed in the same manner as with copper-tin alloys, Riche obtained the following results:

Composition of the alloys examined.			Specific gravity.			
Copper.	Zinc.	Atomic formula.	Found.	Calculated.	Difference. Expansion.	Difference. Contraction.
100.00	—	—	8.890	—	—	—
90.65	9.35	$ZnCu_{10}$	8.834	8.707	—	0.127
85.34	14.66	$ZnCu_6$	8.584	8.602	0.018	—
79.51	20.49	$ZnCu_4$	8.367	8.489	0.122	—
65.98	34.02	$ZnCu_2$	8.390	8.345	—	0.045
59.26	40.74	Zn_2Cu_3	8.329	8.119	—	0.210
49 23	50.76	ZnCu	8.304	7.947	—	0.357
39.27	60.73	Zn_3Cu_2	8.171	7.783	—	0.388
32.66	67.14	Zn_2Cu	8.048	7.679	—	0.369
19.52	80.48	Zn_4Cu	7.863	7.478	—	0.385
10.82	89.18	Zn_8Cu	7.315	7.351	0.036	—
—	100.00	Zn	7.200	—	—	—

Similar figures were obtained by Calvert and Johnson. While with an increasing content of zinc a steady reduction in the specific gravity seems to take place, alloys with 40 to 80 per cent. zinc show quite considerable contraction.

A series of experiments similar to the above mentioned with copper-tin alloys made by Riche show 1, that the specific gravity of copper-zinc alloys richer in zinc (35 per cent.) is increased by mechanical working as well as by tempering, such increase, however, being largely and, occasionally almost entirely, equalized by annealing; and 2, that the specific gravities of alloys poor in zinc (9 per cent.) are not effected by such treatment.

Copper-zinc alloys. Karmarsch has determined the specific gravities of copper-silver alloys in a coined state (coins) to remove the influence of porosity, and found the values given in the subjoined table.

Composition of the alloys examined.		Specific gravities.			
				Difference.	
Silver.	Copper.	Found.	Calculated.	Expansion.	Contraction.
100	—	10.547	—	—	—
94.4	5.6	10.358	10.399	0.041	—
89.3	10.7	10.304	10.351	0.047	—
81.0	19.0	10.164	10.203	0.039	—
75.0	25.0	10.065	10.098	0.033	—
66.3	33.7	9.927	9.951	0.024	—
62.5	37.5	9.870	9.890	0.020	—
56.25	43.75	9.761	9.786	0.025	—
51.21	48.79	9.679	9.706	0.027	—
49.65	50.35	9.650	9.681	0.031	—
42.43	57.57	9.532	9.568	0.036	—
36.7	63.3	9.439	9.482	0.043	—
33.3	66.7	9.383	9.430	0.047	—
30.4	69.6	9.333	9.386	0.053	—
29.5	70.5	9.317	9.371	0.054	—
22.4	77.6	9.203	9.269	0.066	—
22.0	78.0	9.190	9.264	0.074	—
—	100	8.956	—	—	

The series throughout shows expansion, it being most pronounced in alloys richest in copper, then decreases regularly to the alloy with 37.5 per cent. copper and from there on increases again with the increasing content of silver. Nevertheless the greatest expansion does not attain the same extent as that in copper-tin and copper-zinc alloys.

Copper-gold alloys. Roberts has determined the specific gravities of some alloys richer in gold in the form of blanks, and obtained the following values:

Composition of the alloys examined.		Specific gravities.			
				Difference.	
Gold.	Copper.	Found.	Calculated.	Expansion.	Contraction.
100	—	19.3203	—	—	—
98.01	1.99	18.8335	18.8355	—	0.0030
96.88	3.12	18.5805	18.5804	—	0.0001
95.83	4.17	18.3562	18.3605	0.0043	—
94.84	5.16	18.1173	18.1378	0.0205	—
93.85	6.15	17.9340	17.9301	—	0.0039
93.20	6.80	17.7911	17.7956	0.0045	—
92.28	7.72	17.5680	17.6087	0.0407	—
90.05	9.95	17.1653	17.1750	0.0097	—
88.05	11.95	16.6082	16.8047	—	0.0015
86.14	13.86	16.4832	16.4630	—	0.0202
—	100.00	8.725	—	—	—

According to the above table neither regularly progressing expansion nor contraction takes place. In most cases the difference between the found and calculated specific gravities is extremely small, and hence it may be supposed that a change in volume is not caused, at least not in the alloys examined. For practical purposes this is of importance in so far as it allows of calculating the content of gold in a gold coin from its specific gravity.

Silver-gold alloys. Determinations by A. Matthiessen gave the following results:

Composition of the alloys examined.			Specific gravities.			
Silver.	Gold.	Atomic formula.	Found.	Calculated.	Difference. Expansion.	Difference. Contraction.
100.0	—	Ag	10.468	—	—	—
76.5	23.5	Ag_6Au	11.760	11.715	—	0.045
68.7	31.3	Ag_4Au	12.257	12.215	—	0.042
52.3	47.7	Ag_2Au	13.432	13.383	—	0.049
35.4	64.6	AgAu	14.870	14.847	—	0.023
21.5	78.5	$AgAu_2$	16.354	16.315	—	0.039
12.0	88.0	$AgAu_4$	17.540	17.493	—	0.047
8.3	91.7	$AgAu_6$	18.041	17.998	—	0.043
—	100.0	Au	19.265	—	—	—

Hence in alloying the two metals contraction, though to an inconsiderable extent, takes place throughout.

Lead-gold alloys, according to Matthiessen:

Composition of the alloys examined.			Specific gravities.			
Lead.	Gold.	Atomic formula.	Found.	Calculated.	Difference. Expansion.	Difference. Contraction.
100	—	Pb	11.376	—	—	—
91.3	8.7	$Pb_{10}Au$	11.841	11.794	—	0.047
84.0	16.0	Pb_5Au	12.274	12.171	—	0.103
80.8	19.2	Pb_4Au	12.445	12.346	—	0.099
76.1	23.9	Pb_3Au	12.737	12.618	—	0.119
67.7	32.3	Pb_2Au	13.306	13.103	—	0.203
51.2	48.8	PbAu	14.466	14.210	—	0.256
34.6	65.4	$PbAu_2$	15.603	15.546	—	0.057
20.8	79.2	$PbAu_4$	17.013	16.832	—	0.181
—	100	Au	19.265	—	—	—

Hence contraction takes place in all proportions and is considerably greater than in silver-gold alloys.

Silver-lead alloys, according to Matthiessen:

Composition of the alloys examined.			Specific gravities.			
Silver.	Lead.	Atomic formula.	Found.	Calculated.	Difference. Expansion.	Difference. Contraction.
100.0	—	Ag	10.468	—	—	—
67.6	32.4	Ag_4Pb	10.800	10.746	—	0.054
51.0	49.0	Ag_2Pb	10.925	10.894	—	0.031
34.2	65.8	AgPb	11.054	11.048	—	0.006
20.6	79.4	$AgPb_2$	11.144	11.175	0.031	—
11.5	88.5	$AgPb_4$	11.196	11.263	0.067	—
4.5	95.5	$AgPb_{10}$	11.285	11.327	0.042	—
2.0	98.0	$AgPb_{25}$	11.334	11.355	0.021	—
—	100	Pb	11.376	—	—	—

The above table shows a quite regular course. The alloys richest in lead possess a less specific gravity than calculated, the difference rising with the content of silver until the latter amounts to 11.5 per cent. From here on the difference decreases with a further increase in the content of silver, and with 34 per cent. silver contraction instead of expansion takes place, the extent of contraction growing also with the content of silver.

Antimony-tin alloys, according to Long:

Composition of the alloys examined.			Specific gravities.			
Antimony.	Tin.	Atomic formula.	Found.	Calculated.	Difference. Expansion.	Difference. Contraction.
100.0	—	Sb	6.713	—	—	—
92.6	7.4	$Sb_{12}Sn$	6.739	6.752	0.013	—
89.2	10.8	Sb_8Sn	6.747	6.770	0.023	—
88.1	11.9	Sb_4Sn	6.781	6.817	0.036	—
67.7	32.3	Sb_2Sn	6.844	6.889	0.045	—
51.4	48.6	SbSn	6.929	6.984	0.055	—
34.5	65.5	$SbSn_2$	7.023	7.082	0.059	—
26.0	74.0	$SbSn_3$	7.100	7.133	0.033	—
17.4	82.6	$SbSn_5$	7.140	7.186	0.046	—
9.5	90.5	$SbSn_{10}$	7.208	7.234	0.026	—
5.0	95.0	$SbSn_{20}$	7.276	7.262	—	0.014
2.1	97.9	$SbSn_{50}$	7.279	7.281	0.002	—
1.0	99.0	$SbSn_{100}$	7.284	7.287	0.003	—
—	100.0	Sn	7.294	—	—	—

Hence expansion takes place almost throughout, increasing from both ends of the series and reaching the highest extent in alloys containing from 50 to 65 per cent. tin. Deviations from the regular course of the series may probably be due to fortuitous circumstances in the preparation of the alloys.

Antimony-bismuth alloys, according to Holzmann:

Composition of the alloys examined.			Specific gravities.			
Antimony.	Bismuth.	Atomic formula.	Found.	Calculated.	Difference. Expansion.	Difference. Contraction.
100	—	Sb	6.713	—	—	—
54.0	46.0	Sb_2Bi	7.864	7.856	—	0.008
37.1	62.9	SbBi	8.392	8.385	—	0.007
22.7	77.3	$SbBi_2$	8.886	8.888	0.002	—
12.8	87.2	$SbBi_4$	9.277	9.272	—	0.005
8.9	91.1	$SbBi_6$	9.435	9.433	—	0.002
—	100	Bi	9.823	—	—	—

The difference between calculated and found specific gravities is so small that, at least with alloys poorer in antimony, it may be supposed that the volume remains unchanged. A slight contraction seems to take place only with a higher content of antimony.

Antimony-lead alloys, according to Matthiessen:

Composition of the alloys examined.			Specific gravities.			
Antimony.	Lead.	Atomic formula.	Found.	Calculated.	Difference. Expansion.	Difference. Contraction.
100.0	—	Sb	6.713	—	—	—
54.1	45.9	Sb_2Pb	8.201	8.268	0.067	—
37.1	62.9	SbPb	8.989	9.045	0.056	—
22.7	77.3	$SbPb_2$	9.811	9.822	0.011	—
16.4	83.6	$SbPb_3$	10.144	10.211	0.067	—
10.5	89.5	$SbPb_5$	10.586	10.599	0.013	—
5.5	94.5	$SbPb_{10}$	10.930	10.952	0.022	—
2.3	97.7	$SbPb_{25}$	11.194	11.196	0.002	—
—	100	Pb	11.376	—	—	—

Hence, as far as this series extends, expansion takes place throughout in alloying. In alloys with more than 22 per cent. antimony, Riche also found expansion, but contraction in alloys poorer in antimony and richer in lead, the maximum of 0.023 being reached in an alloy with about 90 per cent. lead ($SbPb_5$).

Calvert and Johnson found expansion in all antimony-lead alloys.

Tin-cadmium alloys, according to Matthiessen:

Composition of the alloys examined.			Specific gravities.			
					Difference.	
Tin.	Cadmium.	Atomic formula.	Found.	Calculated.	Expansion.	Contraction.
100.0	—	Sn	7.294	—	—	—
86.1	13.9	Sn_6Cd	7.434	7.456	0.022	—
80.5	19.5	Sn_4Cd	7.489	7.524	0.035	—
73.2	26.8	Sn_2Cd	7.690	7.687	—	0.003
50.8	49.2	SnCd	7.904	7.905	—	0.001
34.1	65.9	$SnCd_2$	8.139	8.137	—	0.002
20.5	79.5	$SnCd_4$	8.336	8.335	—	0.001
14.7	85.3	$SnCd_6$	8.432	8.424	—	0.008
—	100.0	Cd	8.655	—	—	—

The alloys richer in tin plainly show expansion, which, however, disappears when the content of tin amounts to less than about 75 per cent.

Tin-bismuth alloys, according to Carty:

Composition of the alloys examined.			Specific gravities.			
Tin.	Bismuth.	Atomic formula.	Found.	Calculated.	Difference. Expansion.	Difference. Contraction.
100.0	—	Sn	7.294	—	—	—
92.4	7.6	$Sn_{22}Bi$	7.438	7.438	—	—
69.0	31.0	Sn_4Bi	7.943	7.925	—	0.018
62.5	37.5	Sn_3Bi	8.112	8.071	—	0.041
52.7	47.3	Sn_2Bi	8.339	8.305	—	0.034
35.8	64.2	SnBi	8.772	8.738	—	0.034
21.8	78.2	$SnBi_2$	9.178	9.132	—	0.046
12.2	87.8	$SnBi_4$	9.435	9.423	—	0.012
3.3	96.7	$SnBi_8$	9.614	9.606	—	0.008
2.3	97.7	$SnBi_{12}$	9.675	9.674	—	0.001
1.3	98.7	$SnBi_{20}$	9.737	9.731	—	0.006
0.5	99.5	$SnBi_{60}$	9.774	9.792	0.018	—
—	100.0	Bi	9.823	—	—	—

These alloys show contraction almost throughout, it reaching its greatest extent in the alloy with 78 per cent. bismuth, and from there on decreases with an increasing content of bismuth and decreasing content of tin. Riche obtained very similar results, he finding the maximum contraction in the alloy Sn_2Bi_5.

Tin-silver alloys, according to Holzmann:

Composition of the alloys examined.			Specific gravities.			
Tin.	Silver.	Atomic formula.	Found.	Calculated.	Difference. Expansion.	Difference. Contraction.
100.0	—	Sn	7.294	—	—	—
95.1	4.9	$Sn_{18}Ag$	7.421	7.404	—	0.017
90.6	9.4	Sn_9Ag	7.551	7.507	—	0.044
86.5	13.5	Sn_6Ag	7.666	7.603	—	0.063
76.3	23.7	Sn_3Ag	7.963	7.858	—	0.105
68.2	31.8	Sn_2Ag	8.223	8.071	—	0.152
52.2	47.8	SnAg	8.828	8.543	—	0.205
34.9	65.1	$SnAg_2$	9.507	9.086	—	0.421
21.1	78.9	$SnAg_4$	9.953	9.585	—	0.368
—	100.0	Ag	10.468	—	—	—

All these alloys show considerable contraction, which generally increases with the content of silver and reaches its maximum with 65 per cent. silver.

Tin-lead alloys, according to Long:

Composition of the alloys examined.			Specific gravities.			
Tin.	Lead.	Atomic formula.	Found.	Calculated.	Difference. Expansion.	Difference. Contraction.
100.0	—	Sn	7.924	—	—	—
77.0	23.0	Sn_6Pb	7.927	7.948	0.021	—
69.0	31.0	Sn_4Pb	8.188	8.203	0.015	—
52.7	47.3	Sn_2Pb	8.779	8.781	0.002	—
35.8	64.2	SnPb	9.460	9.474	0.014	—
21.8	78.2	$SnPb_2$	10.080	10.136	0.056	—
12.2	87.8	$SnPb_4$	10.590	10.645	0.055	—
8.5	91.5	$SnPb_6$	10.815	10.857	0.042	—
—	100.0	Pb	11.376	—	—	—

All the tin-lead alloys examined show expansion, the

maximum being reached with a content of lead of about 80 per cent. Pillichody obtained similar results, only he found considerably greater expansion (minimum 0.29 in the alloy $SnPb_4$; maximum in the alloy SnPb); Kupffer, Thompson, as well as Calvert and Johnson, found expansion throughout.

Tin-gold alloys, according to Holzmann:

Composition of the alloys examined.			Specific gravities.			
Tin.	Gold.	Atomic formula.	Found.	Calculated.	Difference. Expansion.	Difference. Contraction.
100.0	—	Sn	7.294	—	—	—
96.6	3.4	$Sn_{50}Au$	7.441	7.446	0.005	—
90.7	9.3	$Sn_{15}Au$	7.801	7.786	—	0.015
84.2	15.8	Sn_9Au	8.118	8.092	—	0.026
77.9	22.1	Sn_6Au	8.470	8.452	—	0.018
70.3	29.7	Sn_4Au	8.931	8.951	0.020	—
63.8	36.2	Sn_3Au	9.405	9.407	0.002	—
59.5	40.5	Sn_5Au_2	9.715	9.743	0.028	—
54.0	46.0	Sn_2Au	10.168	10.206	0.038	—
47.0	53.0	Sn_3Au_2	10.794	10.885	0.091	—
37.0	63.0	SnAu	11.833	11.978	0.145	—
22.7	77.3	$SnAu_2$	14.243	14.028	—	0.216
12.8	87.2	$SnAu_4$	16.367	15.913	—	0.454
—	100.0	Au	19.265	—	—	—

This series exhibits a peculiar course: The alloys richest in gold show strong contraction, those with a medium content of gold, expansion, and those lowest in gold, again slight contraction. It must, however, be remarked that with the great difference in the specific gravities of the separate materials constituting the alloys, every small variation in the actual specific gravity, and that upon which the calculation is based, is more perceptible than with approximately equal specific gravities, and hence a small error—especially in the last mentioned contraction—may perhaps be supposed.

Cadmium-bismuth alloys, according to Matthiessen :

Composition of the alloys examined.			Specific gravities.			
Cadmium.	Bismuth.	Atomic formula.	Found.	Calculated.	Difference. Expansion.	Difference. Contraction.
100.0	—	Cd	8.655	—	—	—
61.7	38.3	Cd_3Bi	9.079	9.067	—	0.012
51.8	48.2	Cd_2Bi	9.195	9.181	—	0.014
35.0	65.0	CdBi	9.388	9.380	—	0.008
21.2	78.8	$CdBi_2$	9.554	9.550	—	0.004
11.8	88.2	$CdBi_4$	9.669	9.668	—	0.001
6.3	93.7	$CdBi_8$	9.737	9.740	0.003	—
4.3	95.7	$CdBi_{12}$	9.766	9.766	—	—
—	100.0	Bi	9.823	—	—	—

These alloys show slight contraction, increasing toward the middle of the series until the quantity of both metals is approximately the same.

Cadmium-lead alloys, according to Holzmann :

Composition of the alloys examined.			Specific gravities.			
Cadmium.	Lead.	Atomic formula.	Found.	Calculated.	Difference. Expansion.	Difference. Contraction.
100.0	—	Cd	8.655	—	—	—
77.2	22.8	Cd_6Pb	9.160	9.173	0.013	—
68.2	31.8	Cd_4Pb	9.353	9.364	0.011	—
51.8	48.2	Cd_2Pb	9.755	9.780	0.025	—
35.0	65.0	CdPb	10.246	10.246	—	—
21.2	78.8	$CdPb_2$	10.656	10.663	0.007	—
11.8	88.2	$CdPb_4$	10.950	10.966	0.016	—
8.3	91.7	$CdPb_8$	11.044	11.088	0.044	—
—	100.0	Pb	11.376	—	—	—

This series is not distinct, but expansion, which generally increases with the content of lead, may be inferred from it.

Bismuth-silver alloys, according to Holzmann:

Composition of the alloys examined.			Specific gravities.			
Bismuth.	Silver.	Atomic formula.	Found.	Calculated.	Difference. Expansion.	Difference. Contraction.
100.0	—	Bi	9.823	—	—	—
99.0	1.0	$Bi_{50}Ag$	9.813	9.829	0.016	—
97.8	2.2	$Bi_{24}Ag$	9.820	9.836	0.016	—
96.0	4.0	$Bi_{12}Ag$	9.836	9.848	0.012	—
92.0	8.0	Bi_6Ag	9.859	9.871	0.012	—
88.5	11.5	Bi_4Ag	9.899	9.893	—	0.006
79.4	20.6	Bi_2Ag	9.966	9.949	—	0.017
65.8	34.2	BiAg	10.068	10.034	—	0.034
49.0	51.0	$BiAg_2$	10.197	10.141	—	0.056
32.5	67.5	$BiAg_4$	10.323	10.249	—	0.074
—	100.0	Ag	10.468	—	—	—

The alloys richest in bismuth exhibit slight expansion, but contraction with an increasing content of silver.

Bismuth-lead alloys, according to Carty:

Composition of the alloys examined.			Specific gravities.			
Bismuth.	Lead.	Atomic formula.	Found.	Calculated.	Difference. Expansion.	Difference. Contraction.
100.0	—	Bi	9.823	—	—	—
95.2	4.8	$Bi_{20}Pb$	9.893	9.887	—	0.006
93.5	6.5	$Bi_{16}Pb$	9.934	9.902	—	0.032
88.8	11.2	Bi_8Pb	10.048	9.974	—	0.074
80.0	20.0	Bi_4Pb	10.235	10.048	—	0.137
66.6	33.4	Bi_2Pb	10.538	10.290	—	0.248
50.0	50.0	BiPb	10.956	10.541	—	0.415
33.4	66.6	$BiBb_2$	11.141	10.805	—	0.336
25.0	75.0	$BiPb_3$	11.161	10.942	—	0.219
20.0	80.0	$BiPb_4$	11.188	11.026	—	0.162
16.7	83.3	$BiPb_5$	11.196	11.083	—	0.113
7.7	92.3	$BiPb_{12}$	11.280	11.238	—	0.042
—	100.0	Bi	11.376	—	—	—

These alloys show contraction increasing regularly from both ends of the series, and reaching the maximum in the alloy with 50 parts bismuth and 50 parts lead. Similar results were obtained by Riche. The contraction is considerable and exceeds that of nearly all other alloys.

Bismuth-gold alloys, according to Holzmann:

Composition of the alloys examined.			Specific gravities.			
Bismuth.	Gold.	Atomic formula.	Found.	Calculated.	Difference. Expansion.	Difference. Contraction.
100.0	—	Bi	9.823	—	—	—
97.6	2.4	$Bi_{40}Au$	9.942	9.935	—	0.007
95.4	4.6	$Bi_{20}Au$	10.076	10.046	—	0.030
89.4	10.6	Bi_8Au	10.452	10.360	—	0.092
80.8	19.2	Bi_4Au	11.025	10.840	—	0.185
67.8	32.2	Bi_2Au	12.067	11.659	—	0.408
51.3	48.7	BiAu	13.403	12.898	—	0.505
34.5	65.5	$BiAu_2$	14.844	14.462	—	0.382
—	100.0	Au	19.265	—	—	—

With an increasing content of gold the alloys show at first considerable contraction, which reaches the maximum with about 50 per cent. of gold, and then decreases with a further increase in gold.

Tin-mercury alloys (*tin amalgams*), according to Holzmann:

Composition of the alloys examined.			Specific gravities.			
Tin.	Mercury.	Atomic formula.	Found.	Calculated.	Difference. Expansion.	Difference. Contraction.
100.0	—	Sn	7.294	—	—	—
53.7	46.3	Sn_2Hg	9.362	9.282	—	0.080
36.7	63.3	SnHg	10.369	10.313	—	0.056
22.5	77.5	$SnHg_2$	11.456	11.373	—	0.083
—	100.0	Hg	13.573	—	—	—

These alloys show perceptible and approximately equal contraction. The same results were obtained by Calvert and Johnson.

Lead-mercury alloys (*lead amalgams*), according to Matthiessen:

Composition of the alloys examined.			Specific gravities.			
Lead.	Mercury.	Atomic formula.	Found.	Calculated.	Difference. Expansion.	Difference. Contraction.
100.0	—	Pb	11.376	—	—	—
67.4	32.6	Pb_2Hg	11.979	12.008	0.029	—
50.8	49.2	PbHg	12.484	12.358	—	0.126
34.1	65.9	$PbHg_2$	12.815	12.734	—	0.081
—	100.0	Hg	13.573	—	—	—

General conclusions. All the alloys examined may be divided into three groups:

Group I.	Group II.	Group III.
Alloys which plainly show contraction:	*Alloys which plainly show expansion:*	*Alloys which do not show plainly either expansion or contraction:*
Copper-tin.	Copper-silver.	Copper-gold.
Copper-zinc with 35 to 80 per cent. zinc.	Lead-silver with more than 70 per cent. lead.	Antimony-bismuth.
Silver-gold (slight contraction).	Antimony-tin.	Tin-cadmium with less than 75 per cent. tin.
Lead-gold.	Antimony-lead.	
Lead-silver with more than 30 per cent. silver.	Tin-cadmium with more than 75 per cent. tin.	
Tin-bismuth.	Tin-lead.	
Tin-silver.	Tin-gold with more than 25 per cent. tin.	
Tin-gold with more than 75 per cent. gold.	Cadmium-lead.	
Cadmium-bismuth with more than 10 per cent. cadmium (slight contraction).		
Bismuth-silver with more than 10 per cent. silver.		
Bismuth-lead.		
Bismuth-gold.		
Tin-mercury.		
Lead-mercury with more than 40 per cent. mercury.		

No definite regularity in the behavior of the metals can be recognized. While some metals, for instance, bismuth, gold, tin, produce chiefly contraction, and others, for instance, lead, antimony, expansion, there are still others, such as copper, tin, cadmium, which appear irregularly in all the groups, and there can be no doubt that certain chemical processes or actions of the separate metals upon one another play a role in this respect. If, for instance, a metal is capable of dissolving its own oxides (copper dissolves cuprous oxide, etc.) and decreasing thereby its specific gravity, and it is alloyed with another metal which acts in a reducing manner upon the dissolved oxide, without that the newly formed product of oxidation is dissolved, contraction will evidently take place. But if, on the contrary,

a metal, for instance, silver, possesses while in a liquid state, the power of dissolving oxygen, which is liberated from the pure metal during the process of solidifying, and this metal is alloyed with another metal which is oxidized by the dissolved oxygen and whose product of oxidation is dissolved by the metal bath, (copper), the specific gravity will evidently be decreased in consequence of this solution of oxides, and expansion take place.

From such or similar processes many apparent contradictions or irregularities in the series of specific gravities might also be deduced.

3. Crystallization. It has previously been mentioned that various alloys show a decided tendency towards crystallization, which, however, does not furnish a proof—as has frequently been supposed—of the presence of chemical combinations of the metals with each other.

If the alloy consists of metals which crystallize in the same system, the crystals of the alloy also belong, as a rule, to this system; otherwise the alloy generally crystallizes in one of the systems of the separate metals.

Copper-tin alloys usually crystallize in the hexagonal system. In an alloy of 19 parts copper with 81 parts tin, Rammelsberg found regular hexagonal prisms. From alloys richer in copper (bronzes), crystals several centimeters fn length may, according to Künzel, be obtained by allowing an iron plate to float upon the liquid metal-bath not heated too much above the fusing point. The crystals deposit on the plate with their principal axis at a right angle towards the cooling surface of the plate, and can be lifted together with the latter from the liquid metal.

Copper-zinc alloys crystallize nearly all in octahedrons of the monometric system, and in the hollow spaces of castings octahedral formations of considerable size are not unfrequently found, the composition of which by no means shows always a chemical combination composed according to atomic proportions. On the other hand, an alloy which

corresponds to the chemical formula ZnCu (50.7 parts zinc, 49.3 parts copper) shows a peculiar long-fibrous texture, and according to Calvert and Johnson, crystallizes in prisms frequently over 1 inch in length.

Antimony-zinc alloys in all proportions of from 20 to 70 per cent. zinc yield beautifully developed crystals of the rhombic system; those richer in zinc being generally prisms, and those poorer in zinc, octahedrons.

Gold-silver, lead-silver and silver-mercury alloys crystallize in the monometric system.

Gold-tin alloys with a content of gold between 27 and 43 per cent,, and moreover, in all possible proportions by weight, crystallize in the dimetric system.

Iron-tin alloys crystalize in the dimetric system. Such an alloy containing about 80.5 per cent. tin and 19.5 per cent. iron remains behind, according to Rammelsberg, in quadrangular prisms, if Banca tin is dissolved in hydrochloric acid.

Iron-manganese alloys, which, as a rule, contain in addition 5 to 7 per cent. carbon, frequently crystallize in finely developed rhombic prisms. The largest and most perfect crystals are found in alloys with 30 to 60 per cent. manganese, though alloys richer in manganese also show distinct formations of crystals, while in alloys with less than 25 per cent. manganese the independent crystals are smaller and of more rare occurrence.

For the practice the crystallization of alloys is of importance only in so far as the development of crystals generally goes hand in hand with a deterioration in the properties—decrease in strength, ductility, etc.—and besides crystallization is, as a rule, closely related to liquation. But the more slowly a casting is cooled the more opportunity the metal has to follow its inclination towards crystallization or liquation, and hence, it may be laid down as a general rule that crystallization should be rendered difficult by rapid cooling of the castings.

4. Strength. The tensile strength is most frequently determined, the other kinds of strength, such as compressive strength, etc., as a rule, though not always increasing and decreasing with the tensile strength, and the latter is here meant, when speaking of strength except when otherwise stated.

Like the strength of a pure metal, that of an alloy also depends to a considerable extent on the manipulations to which it has previously been subjected. The strength of many metals and alloys can be more than doubled by mechanical manipulation in the cold state—hammering, rolling, drawing—and this has to be taken into account in comparing the strength of alloyed and non-alloyed metals. It would be a blunder to compare the strength of a cast metal with that of a wire or a wrought bar of an alloy prepared from that metal. The shape and size of the cross-section have also to be taken into consideration; generally speaking, the strength is the greater the smaller the cross-section is.

In regard to the influences exerted upon the strength of metals by alloying the following general law may be laid down:

By the absorption of a foreign body the strength of metals is increased. It grows with the content of the foreign body until the latter has reached a certain proportion which varies in individual cases. When this limit has been passed the strength again decreases, frequently with great rapidity, provided the foreign body itself does not possess greater strength than the metal.

The content of the foreign body at which the above-mentioned turning-point appears varies very much. With some bodies it lies below 1 per cent. of the weight of the alloy; while with others the strength of the alloy only reaches its maximum when the quantity of the foreign body amounts to nearly that of the actual metal.

Metals or metalloids which themselves possess but little

strength may also to a considerable degree increase the strength of a metal with which they are alloyed in definite proportions. Examples of this are quite numerous.

According to Prof. Robert H. Thurston*, the strength of copper may be considerably increased by the addition of tin, though the latter by itself possesses but little strength. The increase in the tensile aud absolute strength appears to attain its maximum with a content of about 17.5 per cent. tin; with a further enrichment in the content of tin it rapidly decreases and finally approaches gradually, though not with entire uniformity, that of tin. The crushing strength, however, reaches its maximum only with 30 per cent. tin. The brittleness of the alloy increases in all cases with the content of tin, and only when the latter considerably exceeds 50 per cent. is there, in this respect, a gradual approach to the properties of pure tin. Since, however, with a content of over 20 per cent. tin, the strength rapidly decreases and brittleness increases in a still greater degree, it is evident that where great strength is a requisite, alloys richer in tin are quite worthless. The torsional strength of copper-tin alloys is also greatest with a content of 17.5 per cent. tin; it decreasing rapidly with a higher percentage.

An addition of aluminium exerts a still more pronounced effect upon the strength of copper than tin. Cast aluminium possesses a tensile strength of about 10 kilogrammes per square millimeter, and cast copper about 19.50 kilogrammes. With aluminium-copper alloys with an increasing content of aluminium, Tetmajer obtained the following results:

Content of aluminium, per cent.....	5.5	8.5	9	9.5	10	11	11.5
Tensile strength in kilos. per sq. mm..	44	50	57.5	62	64	68	80

With this content of aluminium the limit of the utmost strength would appear to have been reached.

*Report on a Preliminary Investigation of the Properties of Copper-Tin Alloys. Washington, 1879.

Small additions of zinc also increase the strength of copper, though in the cast state its tensile strength is not much more than 2.0 kilogrammes per square millimeter and in a rolled state scarcely more than 15 kilogrammes. Its influence shows itself, however in a less pronounced manner than an addition of tin or aluminium. Mallet found the following average values for the tensile strength of zinc-copper alloys:

Content of zinc, per cent.....	10 to 11.5	12 to 25.5	34 to 66	68.5
Tensile strength in kilos. per sq. mm.	18.5	20.0	16.0	3.0

According to these figures the strength decreases rapidly when the content of zinc exceeds 25 per cent. However, Charpy's experiments with rolled test-bars, annealed after rolling, gave the following values:

Content of zinc, per cent.....	0.0	10.1	18.4	30.2	40.4	44.7	49.7
Tensile strength in kilos. per sq. mm.	21.8	24.1	26.8	28.9	38.4	48	10.0

According to these tests the limit of the utmost strength is reached with a content of about 45 per cent. zinc. The sample with 49.7 per cent. zinc could no longer be rolled and had therefore to be tested in a cast state after it had been milled and annealed like the other test-bars.

The increase in strength which can be brought about by alloying is very plainly shown with gold and silver. The usual addition to these metals consists of copper. While according to Karmarsch, hard-drawn wire of pure gold possesses an average strength of 26 kilogrammes per square millimeter and that of copper 39 kilogrammes, gold wire with 10 per cent. copper shows a strength of 45.8 kilogrammes. Pure hard-drawn silver wire possesses an average strength of 36 kilogrammes per square millimeter, while an alloy of 75 parts silver with 25 parts copper shows an average strength of 77 kilogrammes.

By the addition of a third metal to an alloy consisting of two metals it is sometimes possible to bring about an addi-

tional increase in strength. This may be shown by various examples. Copper-zinc alloys in themselves possess, as previously mentioned, less strength than copper-tin or copper-aluminium alloys, but their strength may be remarkably increased by the addition of small quantities of tin, iron, aluminium. Thus Thurston, for instance, found the tensile strength of a cast alloy of 55 parts copper, 43 parts zinc and 2 parts tin equal to 45.7 kilogrammes per square millimeter.* The so-called Delta metal, which is at present much used and will be referred to later on, contains essentially 55 to 60 parts copper, 43 to 39 parts zinc together with 1 to 1.5 parts iron. It is said to possess a tensile strength of 35 kilogrammes per square millimeter†, while a pure zinc-copper alloy shows scarcely more than a strength of 25 kilogrammes. By the addition of 1 part aluminium to a cast alloy of 57 parts copper and 42 parts zinc, the strength of the latter can be increased to more than 40 kilogrammes per square millimeter, and by adding 4 per cent. of aluminium, to more than 60 kilogrammes.

The strength of gold wires alloyed with copper is also still further increased by the addition of a certain quantity of silver as a third metal. According to Karmarsch, hard-drawn wire of 58.3 parts gold, 29.7 parts copper, and 12 parts silver, possesses an average strength of 102 kilogrammes per square millimeter.

Similar cases may frequently be observed. It must, however, be mentioned that by the addition of a third metal a decrease in strength may sometimes be brought about. Tin-copper alloys of great strength may, for instance, suffer in strength by the introduction of zinc. Thus, Uchatius found the tensile strength of cold rolled bars of

*Transactions of American Society of Civil Engineers. Vol. X.

†In Glaser's *Annalen*, Vol. 26, p. 246, the strength of the rolled and annealed alloy is given as 42.8 kilogrammes per square millimeter.

Copper	90	88	89	91	Parts.
Tin	10	10	10	8.5	
Zinc	—	2	1	0.5	
	50.66	30.20	41.70	38.00	kilogrammes per square millimeter.

The difference in this case is so great as to lead to the conclusion that the results were affected by other unknown causes. In fact Künzel found that an addition of 2 per cent. zinc to tin-copper alloys with about 19 per cent. tin rather increases than decreases their strength. Reliable comparisons regarding the possible injurious effect of a third body are, however, difficult to obtain.

In alloying a metal the limit of elasticity increases steadily with the breaking strength and, as a rule, to a greater extent than the strength; limit of elasticity and breaking weight move more closely together. The limit of elasticity usually increases still further when, with the increase of the foreign body added, the highest degree of strength has already been attained, and a decrease in strength reappears; limit of elasticity and strength sometimes finally converge.

This law is not without importance for the employment of alloys. The more closely limit of elasticity and strength lie together, the greater the danger of fracture in case—intentionallly or unintentionally—the limit of elasticity is exceeded when the material is subjected to stress, and the more brittle the material will be. The material is thereby rendered unsuitable as well for mechanical working by forging, rolling, pressing, drawing, as for use for the manufacture of articles subject to shocks and concussion (ordnance, parts of machinery, bells).

Thurston in investigating the strength of copper-tin alloys found

L. OF C.

the proportion $\frac{\text{limit of elasticity}}{\text{strength}}$:

with pure copper	0.518
with alloys with 10 per cent. tin	0.586
with alloys with 12.5 per cent. tin	0.675
with alloys with 23.7 per cent. tin	1.000

Hence, with alloys with 23.7 per cent. tin limit of elasticity and strength are equal and the former cannot be exceeded, without danger of fracture, when the alloy is subject to stress. The alloy does not stand a permanent change of form; it is very brittle. A decrease in this respect appeared only when the content of tin amounted to 74 per cent. and the strength had been reduced to about 4 kilogrammes per square millimeter.

Similar observations have been made with various other alloys, though determinations of the limit of elasticity of different alloys of the same metals have only in isolated cases been made.

The tenacity (as contrasted with brittleness) is more frequently measured by the change in form of the test-piece previous to breaking when tested for strength. Hence, in testing the tensile strength by the elongation, referred to the original length, which takes place; or, though more seldom, by the decrease in the cross-section of the fracture. The greater this change in form is the more mechanical work is consumed for it, and the less the danger of sudden fracture under the effect of a shock.

The aluminium-copper alloys examined by Tetmajer, the strength-values of which have been previously given, showed, when fractured, the following elongations:

Content of aluminium, per cent	5.5	8.5	9	9.5	10	11	11.5
Elongation per cent. of the original length	64	52.5	32	19	11	1	0.5

Of the zinc-copper alloys with various additions of aluminium mentioned on p. 98, the alloy poorest in aluminium

(1 per cent. aluminium; strength 40 killogrammes) showed an elongation of 50 per cent., and the alloy richest in aluminium (4 per cent. aluminium; strength 69 kilogrammes) an elongation of only 6.5 per cent.

Exceptions to this rule are especially perceptible when one of the alloyed metals contains, while in a non-alloyed state, oxygen combinations, for instance, the previously mentioned cuprous oxide in copper, which injure the tenacity and are disintegrated by the metal added, oxygen being evolved. In such cases the tenacity can be increased by the addition of the second metal, and it decreases only when the content of the second metal exceeds a certain proportion. Thus in his investigations of the zinc-copper alloys mentioned on p. 97, Charpy found the elongations as follows:

Content of zinc, per cent.	0.0	10.1	18.4	30.2	40.4	44.7	49.7
Elongation per cent.....	31.6	36.0	41.4	56.7	35.2	18.3	2.0
Strength in kilos.....	21.8	24.1	26.8	28.9	38.4	48.0	10.0

Hence, in this case, the alloy with 30 per cent. zinc proved the most tenacious. However in such researches as well as in the determination of the breaking load, contingencies sometimes play a role.

5. Hardness. Hardness so far as it is applied to the resistance a material opposes to the penetration of a foreign body, for instance, in working with cutting tools, or to a permanent change in the position of its smallest particles, as in forging, pressing, rolling, drawing, forms a special kind of the properties of strength. By alloying metals the hardness is scarcely ever reduced, while in numerous cases it is greater than that of the separate metals constituting the alloys, Two comparatively soft metals frequently yield an alloy of considerably greater hardness than possessed by each separate constituent, and in working metals for articles of use this increase in hardness and consequent power of resisting mechanical wear is frequently the only reason for

alloying them with other metals. This increase in hardness is prominently shown in various copper alloys, and is produced chiefly by tin which in a pure state is comparatively soft.

There is, however, a difference of opinion as to the most reliable method for determining the degree of hardness. As a rule, a pointed tool is used for the purpose of scratching or producing a depression in the surface of the article to be tested while under a fixed load; the less deep the tool penetrates, the harder the material. In this manner the influence of the alloy upon the degree of hardness of the metals has also been frequently determined.

Copper-tin alloys very plainly show this influence. Pure copper is harder than pure tin; nevertheless a content of 5 parts tin in 95 parts copper, renders the alloy almost twice as hard as pure copper. With a further increase in the content of tin, the hardness also increases considerably until the alloy contains about 20 parts tin and 80 parts copper. With a further increase in the content of tin, the hardness remains at first approximately unchanged or at least cannot be measured by reason of the great brittleness of the alloys. This high degree of hardness decreases only when the content of tin amounts to more than 65 per cent.

According to an observation first made by d'Arcet, which has later on been frequently confirmed and utilized for technical purposes, the hardness of copper-tin alloys with 18 to 22 per cent. tin decreases by heating to a red heat and cooling or tempering them in water. Alloys poorer in tin, however, are not sensibly affected by this treatment.

By an addition of iron or manganese the hardness of copper as well as of copper-tin alloys is increased.

Of less importance is the hardening copper experiences by the absorption of zinc. The highest degree of hardness is shown by an alloy of equal parts of copper and zinc, it being about twice that of pure copper. By the addition of zinc to copper-tin alloys, the hardness of the latter may be even somewhat reduced.

Gold and silver are made considerably harder by the addition of copper; the content of the latter with which the highest degree of hardness is attained has, however, not been definitely determined. Karmarsch found that the wear of copper-silver alloys by abrasion in use, which probably is in the inverse ratio to hardness, takes place according to the following proportional figures:

With	99.3	per cent.	silver,	0.7	per cent.	copper, abrasion,	2.97
"	90.0	"	"	10.0	"	" "	1.60
"	75.0	"	"	25.0	"	" "	1.48
"	65.6	"	"	34.4	"	" "	1.31
"	52.0	"	"	48.0	"	" "	1.20
"	31.2	"	"	68.8	"	" "	1.00
"	21.8	"	"	78.2	"	" "	1.045
"		"	"	100.0	"	" "	1.60

Hence, an alloy with 31.2 per cent. silver would be the hardest, and the hardness decrease with an increasing content of silver as well as of copper.

The hardness of lead is considerably increased by alloying with antimony. According to investigations by Calvert and Johnson, a lead-antimony alloy with 12 per cent. antimony is about four times as hard as pure lead, and one with 23 per cent. antimony, about five times as hard. Although by a further increase in the content of antimony the hardness may be raised even to twelve times that of pure lead, such alloys find no technical application on account of their high degree of brittleness.

Lead-tin alloys are harder than pure lead, and when the content of tin exceeds 60 per cent. also harder than pure tin. An alloy of 70 parts tin and 30 parts lead is about one and a half times as hard as pure lead.

Zinc-tin alloys are, according to Calvert and Johnson, harder than tin but none of them attains the degree of hardness of zinc. The hardness increases quite uniformly with the content of zinc.

The hardness of iron is increased by a content of carbon

(steel). A very high degree of hardness, much exceeding that attainable by a content of carbon alone, is imparted to iron by the addition of chromium, tungsten, molybdenum, vanadium, titanium, and nickel. Such alloys are chiefly used as tool steel. Although but relatively small quantities —0.5 to 5 per cent.; seldom more—of these metals are added, their high price makes these alloys rather expensive, so that their use is restricted to certain purposes.

6. *Flexibility.* Flexibility, in a somewhat narrower sense also called *ductility*, is the capacity of certain bodies, especially metals, of undergoing while in a non-fused state, permanent changes in form by the effect of mechanical forces (pull, pressure, etc.) It is closely allied to the above mentioned tenacity in so far as it is measured by the permanent change in form taking place before fracture. For flexibility a certain degree of tenacity is always required because the permanent change in form becomes possible only when the limit of elasticity has been exceeded. The more readily fractures take place thereby, the less flexible the material.

In tests for strength, the tenacity, as previously mentioned, is usually measured by the change in form which the test-piece suffers previous to fracture (elongation in testing tensile strength, compression in testing compressive strength). However, in addition to the tenacity of the body, flexibility depends on various other conditions. The extent of the change in form which a material can stand without undergoing fracture has first to be taken into account, especially the smallness of the cross section to which it can be stretched or drawn out. Gold and silver are considered the most flexible of all the metals and chiefly so because no other metal can be stretched to such thin cross-sections as shown by gold-leaf and silver-leaf. There has further to be considered the extent of the mechanical work which is required for giving the material a definite form, and this depends partially on the limit of elasticity of the

material. The lower the limit of elasticity lies and the less resistance the particles offer to their being shifted after passing the limit of elasticity, the less comsumption of work for the change of form will be required, and the more flexible the material appears. However, the greater the strength the less danger there is of the material suffering fracture after the limit of elasticity has been passed. In this sense the difference between limit of elasticity and strength is also of importance for the degree of flexibility. The temperature at which the material is worked has also to be taken into account. Many metals possessing but little flexibility at the ordinary temperature, become more flexible by heating (iron, copper), while others lose thereby on flexibility (brass, German silver).

Although, from what has been said it is impossible to establish a scale of flexibility of the metals and alloys appropriate to all cases, observation has shown that, generally speaking, *the purest metals possess the greatest flexibility, and that by alloying this property is diminished and sometimes almost reduced to naught.*

The flexibility of copper in the cold state is materially injured by a very small quantity of lead—perceptibly so already with 0.25 per cent.—and still more so when heated. Copper alloys with 6 per cent. tin have, while in a cold state, almost entirely lost their flexibility, but when heated show a moderate degree of it if their content of tin is not much over 15 per cent. On the other hand, while zinc increases the strength and hardness of copper to a far less extent than tin, its effect upon the flexibility of copper is far less, zinc-copper alloys with equal proportions by weight of both metals possessing still a certain, though quite low, degree of flexibility.

Gold and silver also become less flexible when alloyed with other metals, and are therefore used in a pure state when the highest degree of flexibility is demanded, for instance in the preparation of gold leaf and silver leaf. The

least injurious effect is produced by copper, though both of the metals thereby lose perceptibly in tenacity and flexibility.

A small content of zinc appears to have a beneficial effect upon the flexibility of many gold-copper and silver-copper alloys, especially when they contain much copper. According to Peligot, gold-copper alloys with 58 to 60 per cent. gold, for instance, which by themselves are quite difficult to work, become more ductile by replacing 5 to 7 per cent. of copper with the same quantity of zinc; thus 58 to 60 per cent. gold, 35 to 37 per cent. copper, 5 to 7 per cent. zinc. However, if the content of zinc exceeds this limit, the ductility decreases. Alloys with more than 1 to 2.5 per cent. gold also become less ductile by small quantities of zinc.

The effect of bismuth is especially injurious to the flexibility of many metals—gold, silver, lead, tin, copper, etc.—a content of 0.05 per cent. of it being sufficient to render each one of these metals useless for purposes requiring a high degree of flexibility. Antimony and arsenic may also produce an injurious effect even in small quantities. The flexibility of zinc is especially impaired by small quantities of tin, a content of 0.1 per cent. of this metal producing a remarkable effect in this respect.

An exception to the rule according to which pure metals are more flexible than alloyed ones would seem to be found in cases where the flexibility as well as the tenacity has been impaired by the absorption of oxygen and the separation of this content of oxygen has been effected by the addition of another body. Thus, according to Charpy's investigations, the flexibility of copper containing oxygen can be increased by a moderate addition of zinc, and similar cases have been frequently observed. However, every excess of the addition not required for the purpose diminishes the flexibility instead of increasing it; more in one case, less in another.

7. Casting Capacity. The most important property of metals for the manufacture of many articles, is their ability, when in a melted state, of being cast in moulds and filling completely every portion, even the smallest cross-section, of the latter. However this quality again depends on several other properties.

a. *Melting temperature.* The lower the melting temperature, the more readily the material to be cast can be converted into the liquid state and the more convenient its use for casting.*

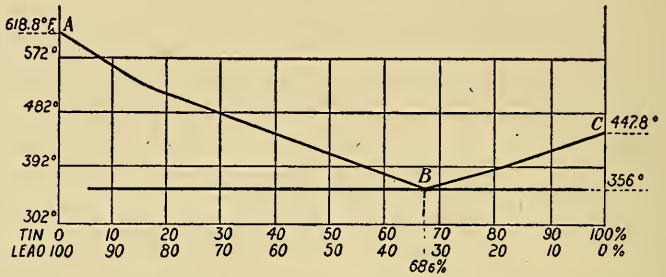
By alloying the melting temperature of metals is frequently lowered, i. e., the melting temperatures of the alloys are lower than they would be according to calculation if computed from the melting temperatures of the constituent metals and their proportions by weight. Furthermore, by the addition of a metal melting at a higher temperature to one melting at a lower one, the melting temperature of the latter is frequently lowered instead of raised. The melting temperature begins again to rise only when the content of the more refractory metal in the alloy exceeds a certain limit at which lies the lowest melting temperature attainable—hence when the composition of the eutectic alloy is reached. There are numerous examples of this.

Tin melts at 446° F.; lead at 618.8° F. By alloying certain quantities of lead with tin, the melting temperature of the latter can be still further lowered, its lowest point being reached with an alloy of about 31 parts lead and 69 parts tin (melting temperature 356° F.). It rises again with an increase in the content of lead approaching more and more that of pure lead. By connecting the melting points of the various lead-tin alloys by a line, the broken shape ABC, Fig. 6 is obtained. The straight line lying at 356° F. indi-

* By melting temperature is understood the temperature at which all the constituents which may possibly have been separated by liquation become again liquid.

cates the eutectic temperature common to all lead-tin alloys at which the eutectic alloy, which for the longest time remains liquid during solidification and liquation, congeals.

Fig. 6.



It has previously been stated that the melting temperature (618.8° F.), is lowered by the absorption of small quantities of silver (melting temperature 1760° F.), the lowest melting temperature—about 572° F.—being that of an alloy with about 4 per cent. silver. With a larger, as well as with a smaller, content of silver the melting temperature is higher.

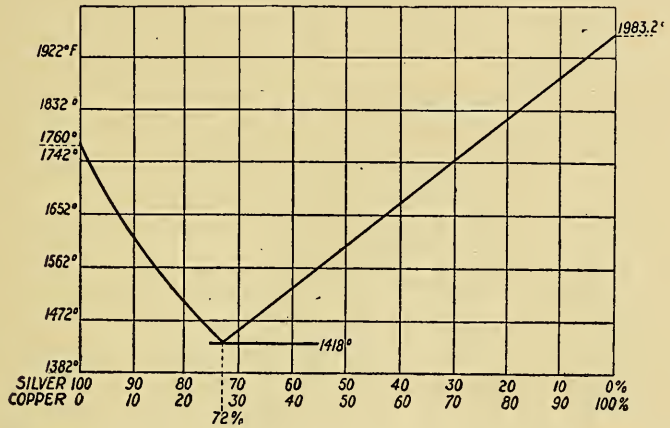
But few determinations of the melting temperatures of the more refractory metals have been made. Copper melts at 1983.2° F.; silver at 1760° F. The eutectic alloy of both metals contains, as previously stated, 72 parts silver and 28 parts copper, and congeals at 1418° F., see Fig. 7.

The melting temperature (2732° F.) of pure iron is considerably lowered by the addition of various bodies, especially so by carbon which by itself is infusible in our ordinary fires. The melting temperature of iron is reduced about 212° F. by the absorption of 1 per cent. carbon. Iron with 4 per cent. carbon melts already at 1985° F.

On the other hand there are alloys whose actual melting temperatures agree quite well with those obtained by calculation, or are even somewhat higher. If, in the first case, all the alloys of the same group behave in the same man-

ner, the line in which the melting temperatures of the alloys converge and which connects the melting temperatures of the pure metals, is a straight one; to this belong, for instance, the alloys of gold (melting temperature 1913° F.) and of silver (melting temperature 1760° F.) In the

FIG. 7.

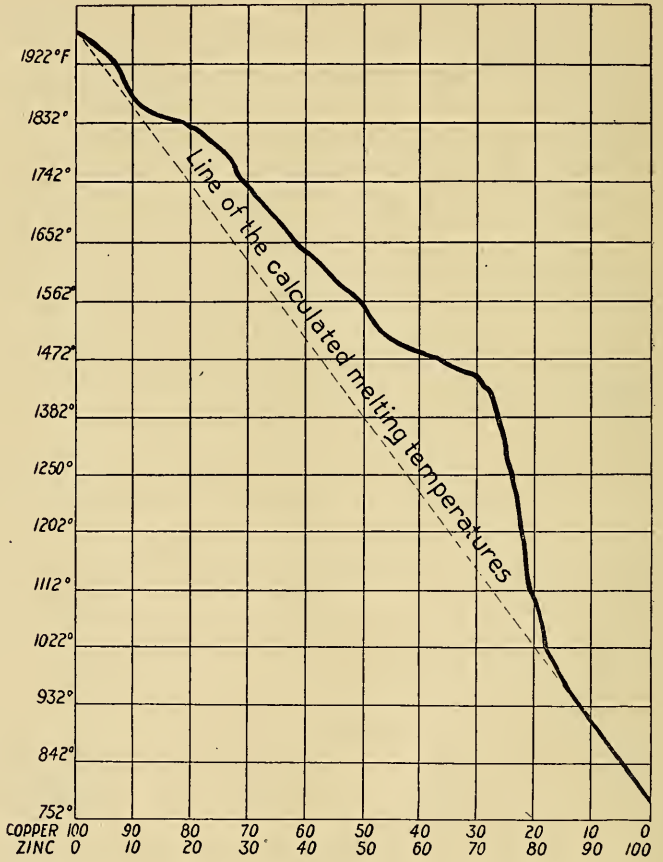


second case the line of view of the melting temperatures lies above the straight line drawn between the melting temperatures of the separate metals. Copper-zinc alloys may be mentioned as an example. Zinc melts at 779° F., and copper at 1983.2° F. Maurice Lucas found the following melting temperatures of alloys to which for the sake of comparison are added those found by calculation.

Copper per cent.	Zinc per cent.	Melting temperature found °F.	Melting temperature calculated °F.
90.5	9.5	1868	1868
80.3	19.7	1832	1745.6
69.5	30.5	1733	1614.2
60.2	39.8	1616	1502.6
51.0	49.0	1533.6	1391
39.7	60.3	1493.6	1256
31.0	69.0	1457	1171.6
25.1	74.9	1292	1083.2
20.4	79.6	1097.6	1023.8

Fig. 8 shows the line of melting temperatures. There being no eutectic temperature from the sharp curve of the line at about 30 per cent. copper, the presence of a more intimate chemical combination may be inferred, the composi-

Fig. 8.



tion of which would correspond to the formula Zn_2 Cu (with 32.8 per cent. copper and 67.2 per cent. zinc), and which during solidification separates from the alloys richer in zinc. This alloy, as confirmed by various investigators,

is distinguished from the other alloys of this group by its great brittleness, color, and chemical behavior.

Finally there are alloys of which single ones stand out prominently from the entire series with a higher melting temperature than the adjoining ones. As an example of this may serve the alloys of copper and antimony, the melting temperatures of which are represented in the line of view

FIG. 9.

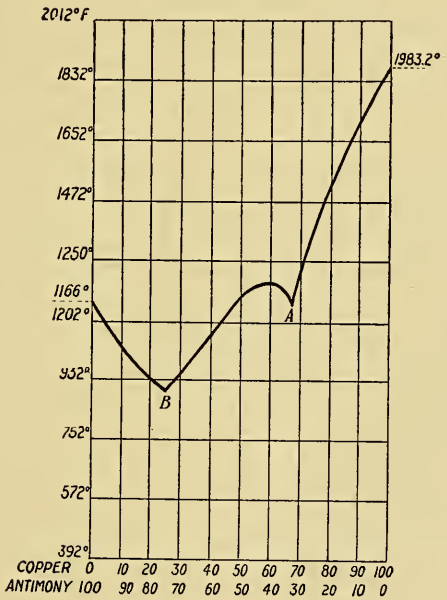


Fig. 9. The alloy with about 51.5 per cent. copper and 48.5 per cent. antimony has a higher melting temperature than the nearest ones richer in copper and richer in antimony. It is considered a chemical combination of the formula $SbCu_2$. The series has two eutectic points. A eutectic alloy consisting of copper and the compound $SbCu_2$ solidifies at *A*, and one consisting of antimony and the compound $SbCu_2$, at *B*.

By the addition of a third or fourth metal to an alloy, a

further reduction in the melting temperature can be effected. Therefore, generally speaking, *the greater the number of constituents of which the alloys consist, the farther the actual melting temperatures of the alloys lie below those found by calculation.* This rule is frequently made use of in the manufacture of very fusible alloys, it being possible by combining several metals in suitable proportions by weight, to make alloys which melt in boiling water. An alloy of 8 parts lead, 3 parts tin, 8 parts bismuth (Rose's metal) melts at 203° F., and another of 8 parts lead, 4 parts tin, 15 parts bismuth, 3 parts cadmium (Wood's metal), already at 154.4° F.

b. *Fluidity.* In addition to the melting temperature the degree of fluidity of a melted metal also exerts an influence upon its casting capacity. The more thinly-fluid it is, the more readily and the more completely it fills the thinnest cross-sections of the mould. To be sure its fluidity is partially dependent on the degree of overheating above the melting temperature in melting, and the lower the latter is the more readily a thinly-fluid state will be obtained. However, independent of this there is no conformity in the behavior of the metals. Just as oil is more thickly-fluid than water even when both are to the same extent heated above their boiling points, one metal is more thickly-fluid than another. Such as gradually soften (copper, wrought iron, etc.) as a rule are also more thickly-fluid in a melted state than those which melt suddenly (bronze, cast iron). However, as a rule, alloyed metals pass less gradually into the fluid state than pure metals, and this is without doubt closely connected with the fact observed in foundry practice that alloys—at least generally speaking—are more thinly-fluid than non-alloyed metals. On the other hand some metalloids, especially oxygen and sulphur, render many metals by which they have been absorbed thickly-fluid. Copper and bronze containing oxygen are more thickly fluid than when free from it, and iron containing sulphur is more thickly-fluid than when free from it.

c. *Development of gases.* The casting capacity of a metal is materially impaired if it possesses the property of developing gases while in a fluid state. If this development of gas takes place shortly before solidification the gases can no longer escape, and the resulting casting is full of gas-bubbles. On the other hand, if the metal previous to complete solidification passes through a dough-like condition, it swells up under the pressure of the developing gases, scatters when solidifying with a free surface, and becomes unfit to sharply fill any mould. Since the volume of gases increases materially with the temperature, this process is more plainly perceptible with refractory metals than with those more readily fusible.

This feature frequently observed in casting metals may be ascribed to various causes. It may sometimes be due to gases in solution which shortly before the metal passes into the solid state reassume their gaseous form. Various metals (iron, copper) dissolve hydrogen and in melting find abundant opportunity for absorbing it. Nitrogen may also in certain quantities be dissolved by liquid metals, and some metals, for instance, silver, dissolve oxygen without entering into a more intimate combination with it.

Whether or not and in what direction the capacity of metals to dissolve gases is changed by alloying has thus far not been definitely determined. Observations made in casting lead, however, lead to the conclusion that, as a rule, alloyed metals are less capable of dissolving gases than pure metals. The development of dissolved gases may, however, be sometimes prevented by adding to the metal a body which enters with the dissolved gas into a non-volatile combination which does not again disintegrate. Thus, for instance, the oxygen dissolved by fluid silver escapes with violence shortly before solidification, and frequently produces vigorous scattering, and in every case renders the casting of pure silver a difficult process. If, however, copper be alloyed with the silver, an adequate portion of it combines with the absorbed

oxygen to cuprous oxide which, though it remains dissolved in the metal, does not disintegrate; the development of gas is thus avoided if not caused by other conditions. The greater the proportion of copper to silver the more complete the result will be. Zinc, possessing a stronger tendency towards combining with oxygen, acts still more vigorously than copper.

The gases, however, originate not less frequently from a chemical process in the interior of the liquid metal itself, their formation being first caused thereby. If, for instance, in addition to dissolved oxides—or under circumstances in addition to oxygen which was simply in solution—the metal contains other substances which enter into new gaseous combinations with the oxygen present, a development of gas must by this process be brought about. This development takes place very rapidly if the body combining with the oxygen has a strong affinity for the latter and is present in great excess. It progresses, however, more gradually, and for this very reason is more detrimental to the casting capacity, when the affinity for oxygen of the second body is only slightly greater than that of the metal whose oxide was dissolved, and when it is present in the metal-bath in a greatly diluted state. Thus, for instance, commercial copper contains in addition to certain quantities of cuprous oxide, certain quantities of cuprous sulphide; both of these bodies act one upon the other, gaseous sulphurous acid being thereby formed. The cuprous sulphide is, however, present in the liquid metal in a greatly diluted state and the action does not take place suddenly but progresses very gradually, so that gas is uninterruptedly evolved from the melted copper rendering the latter unfit for the manufacture of castings. By calculating the volume which definite quantities of sulphurous acid occupy in the solidifying temperature, it will be readily understood that even an apparently very small content of sulphur is capable of producing perceptible effects. Iron, as well as nickel, always

contains carbon; if now, in addition to carbon, oxygen is present in the metal, the formation of carbonic oxide is caused by their reciprocal action which, like sulphurous acid in the above-mentioned case, may make the metal unfit for casting purposes.

The development of gas must stop if, in such cases, the metal is alloyed with a body which by reason of its stronger affinity for oxygen attracts the latter and the oxide of which is either separated in an insoluble state in the metal-bath, or at least is no longer disintegrated in the manner previously described. With copper, for instance, this result is attained by the addition of zinc; aluminium, phosphorus or silicon acting still more vigorously. With nickel an addition of zinc also answers the purpose, though magnesium is still more effective. With iron, manganese is as a rule used for the disintegration of the dissolved ferrous oxide, but as the resulting manganous oxide is itself again affected by the carbon present, though somewhat more slowly than the ferrous oxide previously present, an entirely complete result is not attained. The object is however accomplished with greater certainty by aluminium and in fact large quantities of this metal are now used for this purpose; but an excess of the added aluminium remaining in the iron makes the latter thickly-fluid and also impairs its mechanical behavior, and must therefore be avoided.

From what has been said it is evident that by suitably alloying a metal its capacity for developing gases while in a liquid state can be decreased or entirely overcome.

d. *Shrinkage.* When a liquid metal congeals it at first expands like freezing water and consequently the congealed portion floats upon the liquid metal like ice upon water. This, however, as cooling progresses, is followed by a contraction which is nearly always greater than the previous expansion. Hence the articles produced by casting are, when cold, smaller in dimension than the moulds which served for the reception of the liquid metal. This process is called *shrinkage.*

In many respects the shrinkage of metals renders the production of serviceable castings more difficult, and the greater the degree of shrinkage the more this fact becomes apparent. If a casting has in different portions cross-sections of varying thickness which do not simultaneously congeal and shrink, a strain or even a crack may be formed in the casting, but where the metal remains liquid the longest, hence usually in the center of the casting, a hollow space is formed which may render the article entirely useless. In casting liquating alloys accumulations of more readily fusible alloys may easily form in this hollow space.

A law according to which the degree of shrinkage of alloys could be deduced from that of the separate metals cannot be laid down. Alloys frequently shrink to a greater extent than each of their constituents. Pure copper, for instance, shrinks but little*; pure tin $\frac{1}{147}$, pure zinc $\frac{1}{80}$. On the other hand a copper-tin alloy with 10 per cent. tin shrinks $\frac{1}{130}$; with 20 per cent. tin $\frac{1}{65}$; and a copper-zinc alloy with 30 per cent. zinc $\frac{1}{62}$. The degree of shrinkage of tin-lead alloys is quite small and increases with the content of lead. (Degree of shrinkage of pure lead $\frac{1}{92}$).

8. *Conductivity for heat and electricity.* Good conductors for heat are, as a rule, also good conductors for electricity, and *vice versa*. Amongst the metals silver is considered the best conductor for heat and electricity; next comes pure copper, then gold, etc.

Experiments, as well as observations in using metals, have shown that the purest metals are throughout the best conductors and by alloying their conductivity is almost always impaired. According to Matthiessen's investigations, lead, tin, cadmium and zinc are the only metals whose conducting power for electricity is not materially impaired when alloyed with one another, but corresponds to that

*Pure copper is generally not used for casting and an accurate determination of its degree of shrinking is connected with difficulties by reason of its tendency to develop gases in casting and swelling up thereby.

found by calculation. The conducting power of these metals, however, decreases also when they are alloyed with other metals.

It becomes here also evident that, similar to the effect of alloying upon other properties, the conductivity of a less good conductor may be still further decreased by alloying even with a good conductor.

Taking for instance the conductivity of silver for heat, as well as, for electricity as 100, Wiedmann found the conductivity of:

Copper for heat = 73.6; for electricity = 79.3
Zinc for heat = 28.1; for electricity = 27.3

and that of an alloy of 2.1 parts copper and 1 part zinc, for heat = 25.8, for electricity = 25.4.

Very small quantities of a foreign body are frequently sufficient to effect a considerable decrease in conductivity. According to Matthiessen and Holtzmann, the electrical conductivity of pure copper is diminished 27 per cent. by the absorption of only 0.13 per cent. of lead; 40 per cent. by 3.2 per cent. of zinc; 14 per cent. by 2.45 per cent. of silver; 80 per cent. by 4.90 per cent. tin; 86 per cent. by 2.80 per cent. arsenic; and 92 per cent. by 2.50 per cent. phosphorous.

Hampe found that the conductivity of copper may be diminished 50 per cent. by 0.35 per cent. arsenic, and about 25 per cent. by 0.5 per cent. silicon.

In such cases, previously referred to, where a metal concontains its own oxide in solution, the latter may, like another alloyed body impair the conductivity. Matthiessen and Holtzmann found that copper which had become oxidized by melting in the air conducted electricity only in the proportion of 63.37 to 93.00 as compared with copper whose content of oxygen had been destroyed by the action of hydrogen gas. The conductivity might possibly be increased by removing the content of oxygen from such a

metal in the manner previously referred to, *i. e.* by the addition of a body which by reason of its greater affinity for oxygen combines with the latter, and the oxide of which is insoluble in the metal-bath. However, without an excess of such an addition, a complete separation of the oxygen is scarcely possible and there is then danger of this excess exerting just as an injurious, or still more injurious, effect than the oxygen originally present. An addition of phosphorus to copper for the purpose of increasing the conductivity by destroying the cuprous oxide present would, for instance, be scarcely a success, since, as shown by the figures given above, a very small quantity of phosphorus in excess greatly diminishes the conductivity. As shown by Hampe's investigations, an addition of silicon, which has recently been frequently used in the manufacture of conducting wires, also impairs to a considerable extent the conductivity, and the actual object of such an addition is very likely that of increasing the strength of the wire. The problem of finding a suitable addition which will not impair the conductivity has thus far not been solved.

9. Color. Regarding the color of alloys, it may also be said that the intensity of the effect produced by the addition of determined quantities of one metal to another is not equally strong throughout, but shows considerable variations; the color of an alloy does not always form the compound color from the colors of the alloyed metals, but frequently exhibits independent tones. While, for instance, in copper-silver alloys the color of the one metal passes quite regularly into that of the other, and hence forms an actual compound color, in some copper-tin alloys, and still more so, in some copper-zinc alloys with a comparatively high content of copper, the red color disappears almost completely, being replaced by a yellow shade which cannot be produced by simply mixing red and white or red and gray.

The diversity in color of the metals used for technical

purposes is not very great, one metal, copper, being red and another, gold, yellow; the rest are either white or pale gray, in the various shades of the pure white of silver and tin to the pale gray of lead, platinum, etc. Two or more white metals alloyed with one another always give white alloys.

White metals alloyed with the red copper give reddish white, reddish yellow, pure yellow, gray or white alloys. White metals alloyed with gold give pale yellow, greenish or white alloys.

As previously mentioned, the intensity of coloration produced in an alloy by the addition of one or another metal, varies considerably. For the metals more frequently used for colored alloys, the following scale may be adopted:

Tin, nickel, aluminium,
Manganese,
Iron,
Copper,
Zinc,
Lead,
Platinum,
Silver,
Gold.

Each metal in this series standing before another exerts a stronger influence upon the color than the succeeding one, so that the color of the latter frequently disappears by the addition of comparatively small quantities of the former.

However, the different shades of color do not appear gradually and uniformly with the increase or decrease in the content of the one metal, transitions by leaps or bounds being frequently observed, and it may even happen that an alloy with a larger quantity of a white coloring metal may show a darker tone of color than the same alloy with a smaller quantity of the same metal.

The varying intensity of coloration produced by copper,

tin and zinc, may be very plainly recognized by a comparison of the scale of color of copper-tin and copper-zinc alloys.

Copper-tin alloys.			Copper-zinc alloys.		Copper-tin-zinc alloys.		
Content of copper.	Content of tin.	Color.	Content of zinc.	Color.	Content of tin.	Content of zinc.	Color.
95	5	Red yellow, gold-like.	5	Red, almost copper color.	—	—	—
90	10	Reddish, gray-yellow.	10	Rellowish, red brownish.	—	—	—
84	16	Reddish yellow,	16	Red yellow.	5	11	Orange red.
80	20	Reddish gray.	20	Reddish yellow.	4	16	Orange yellow.
78	22	Yellow gray.	22	Reddish yellow.	4	18	Orange yellow.
75	25	Reddish white.	25	Pale yellow.	—	—	—
73	27	Reddish white.	27	Yellow.	4	23	Pale orange.
70	30	White.	30	Yellow.	3	27	Pale yellow.
65	35	Bluish white.	35	Deep yellow.	3	32	Light yellow.
62	38	Bluish gray.	38	Deep yellow.	—	—	—
59	41	Gray.	41	Reddish yellow.	—	—	—
50	50	Pale gray.	50	Handsome gold yellow.	—	—	—
40	60	Gray white.	60	Bismuth gray, with strong luster.	—	—	—
30	70	Gray white.	70	Antimony gray.	—	—	—
20	80	Whitish.	80	Zinc gray.	—	—	—
10	90	Whitish.	90	Zinc gray.	—	—	—

From the above table it will be seen that, while the color of copper, vivid by itself, is almost completely covered by a content of 30 per cent. tin, it is converted by the same quantity of zinc first into yellow, and about 60 per cent. zinc is required to make it entirely disappear. The fact that in copper-zinc alloys with 25 to about 35 per cent. zinc the color appears pure yellow (brass-yellow) and with a still higher content (up to 50 per cent.) of zinc golden yellow, is also of interest and considerable practical importance. Still warmer tones of color are obtained, as shown in the third column of the table, by replacing in the alloys richer in copper (70 to 80 per cent. copper) a portion of the zinc by tin.

The great coloring power of nickel is best shown in nickel coins, which contain 75 per cent. copper and 25 per

cent. nickel. Notwithstanding the large content of copper, the color of the latter has entirely disappeared.

Gold possesses but slight coloring power. Gold-silver alloys with 64 per cent. gold show a greenish-yellow color, and with 30 per cent. gold a perfectly white color like fine silver. When gold is alloyed with copper, the gold color disappears completely with about 75 per cent. copper, the alloys exhibiting the red color of rosette copper, while in a silver-copper alloy with the same quantity of copper, the content of silver can be plainly recognized.

10. Resistance to chemical influences. A knowledge of the resistance of alloys to chemical influences is of considerable practical importance. Nearly all articles of metal and alloys are exposed to the action of gases contained in the atmosphere (besides the quite indifferent nitrogen: oxygen, carbonic acid, aqueous vapor; in inhabited localities nearly always sulphuretted hydrogen, ammonia, etc.), and many of them to that of rain and snow, while utensils for culinary and technical purposes are in addition affected by acid, alkaline, saline, or fatty fluids. For the manufacture of such utensils it might be desirable, as regards other properties, to alloy the metal to be used for the purpose with another, but the question is whether such an alloy possesses the same power of resisting chemical influences as the pure metal. Thus, for instance, tin containing lead is preferable in many respects to pure tin, it being harder, stronger and filling the moulds better in casting; but if the alloy is to be used for kitchen utensils, drinking vessels or similar purposes, the important question arises whether, in view of the poisonous properties of lead it is capable of resisting in the same degree as pure tin the chemical influences to which it may be exposed in use.

But few experiments have been made to determine the behavior of alloys in this respect. It is generally found that the action of the atmosphere is less severe on alloys than on their component metals. An instance of this is the ancient

bronze statues and coins, some of the latter of which have their characters still legible, although they have been exposed to the effects of air and moisture for upwards of twenty centuries.

The action of the atmosphere on an alloy heated to a high temperature is sometimes quite energetic, as is shown in the alloy of 3 parts lead and 1 of tin, which, when heated to redness, burns briskly to a red oxide. When two metals, for instance copper and tin, which oxidize at different temperatures, are combined, they may be separated by continued fusion with exposure to the air. Cupellation of the precious metals is a like phenomenon.

By alloying a metal with another the chemical action of a body upon the alloy is frequently reduced to a less degree than would correspond to the simple dilution of the metal, and two metals, which in a pure state are very sensitive to chemical influences, may even show a comparatively great power of resisting these influences when alloyed in definite proportions with one another. However, two alloys composed of the same metals, but in different proportions, may, in this respect, exhibit considerable variations, and it may happen that an alloy with a larger content of a metal possessing but slight power of resisting certain influences, may be less attacked by the same agents than another alloy with a smaller content of the same metal.

Some investigators have considered this peculiarity of some alloys an indication of the presence of actual chemical combinations. However, a contrary behavior has also been frequently observed. Thus, St. Claire Deville found that a lead-platinum alloy, which he kept in a closet, was entirely decomposed by the action of the air, the lead being converted into lead carbonate (white lead), while a piece of pure lead lying alongside it remained unchanged. Among the silver-copper alloys, that containing 25 per cent. of copper tarnishes to a greater degree in air containing sulphuretted hydrogen than pure silver, etc.

Calvert and Johnson have investigated the resistance of different copper-tin and copper-zinc alloys to acids and salts, and made the remarkable observation that nitric acid of 1.14 specific gravity dissolves the two metals in an alloy of zinc and copper in the exact proportion in which they exist in the alloy employed, while an acid of 1.08 specific gravity dissolved nearly the whole of the zinc and only a small quantity of the copper. Hydrochloric acid of 1.05 specific gravity, which readily dissolves zinc, was found to be completely inactive on all alloys of copper and zinc containing an excess of copper, and especially on the alloy containing equivalent proportions of each metal. Zinc was found to have an extraordinary preventive influence on the action of strong sulphuric acid on copper. The alloy Cu_4Zn_3 (with 56.5 per cent. copper) was but little attacked by concentrated hydrochloric or nitric acid, and not at all by sulphuric acid.

Copper-tin alloys were found to resist the action of nitric acid more than pure copper, but the preventive influence of tin presents the peculiarity that the action of the acid increases as the proportion of tin increases; thus the alloy $CuSn_5$ is attacked ten times more than the alloy CuSn.

Among the copper-tin-zinc alloys the two alloys

$Cu_{18}SnZn$ with 86 per cent. copper, 9 per cent. tin, 5 per cent. zinc.
$Cu_{10}SnZn$ " 77 " " 14.5 " " 8 " "

were found to be only slightly attacked by strong nitric or hydrochloric acid, and, hence, behaved similarly to the above-mentioned alloy Cu_4Zn_3. The resistance of these alloys against the action of nitric acid deserves special attention, since the acid readily attacks each of the separate metals.

Regarding the influence of sea water upon copper-zinc and copper-zinc-tin alloys, Calvert and Johnson found that from pure copper-zinc alloys zinc is chiefly dissolved, the copper being therefore protected by an addition of zinc; and that in the ternary alloys of the mentioned metals, the

solution of zinc is smaller and that of copper considerably larger than in copper-zinc alloys. Hence by the addition of tin the zinc is protected and the copper more exposed, though with an equivalent proportion of copper a reduction in the total effect could not be recognized. On the other hand, the action of sea water is weakened by a small addition of lead and iron to copper-zinc alloys (see Muntz metal).

Articles of copper-tin alloys richer in copper, when exposed for a long time to the action of the air, acquire a beautiful pale green or brownish crust called *patina*, consisting mostly of the hydroxides and carbonates of the component metals. This patina is highly esteemed, partly on account of the beautiful appearance it presents, and partly as a characteristic of antique articles, and it is sought to promote its formation partly by a suitable choice of the alloy and partly by the use of chemical agents. Upon an alloy consisting of Cu 89.78, Sn 6.83, Pb 1.85, Co, Ni 0.90, Fe 0.28, J. Schuler found a patina of the following composition:

SnO_2	49.13
CuO	22.46
PbO	3.53
$Fe_2O_3Al_2O_3$	1.75
CO_2	6.35
H_2O	8.48
Organic substance	0.76
H	0.65
Insoluble matter	6.16

or, omitting the accidental foreign substances (organic substances, sand, etc.):

SnO_3H_2	60.92
$CuCO_3.CuO_2H_2$	34.55
$(PbCO_3)_2PbO_2H_2$	4.51

It is remarkable that in this patina the proportion of copper to the other metals is much smaller than in the bronze.

In *copper-silver alloys* the copper may protect the silver from the attack of single agents, but the silver, even when present in excess, does not protect the copper. Thus copper is dissolved by acetic acid from alloys with 80 per cent. and upward of silver, a fact which deserves attention in using utensils of silver alloyed with copper for household purposes. By boiling copper-silver alloys with dilute sulphuric acid, the greater portion of the copper is dissolved, while nearly all the silver remains behind. It has previously been mentioned that the action of sulphuretted hydrogen is more pronounced upon silver alloyed with copper than upon pure silver; the article becoming covered first with a yellowish and then a brownish coat, which finally turns blue.

In *gold-silver alloys* the gold, if present in excess, may weaken or entirely overcome the action of certain acids upon silver. While from alloys poor in gold all the silver may be extracted by sulphuric acid, an alloy containing more than 50 per cent. gold is not affected.

The action of acids and salt solutions upon *lead-tin alloys* has been more thoroughly investigated on account of the poisonous properties of lead, vessels of tin containing lead being much used for household and commercial purposes. Pleischl, Roussin, Reichelt, and others have shown that acetic acid and common salt solution, or a mixture of both, dissolve lead from lead-tin alloys even if they contain but 2 per cent. of lead, the quantity of lead dissolved increasing, of course, with the content of lead in the alloy, and depending on the time of action. It is a curious fact that some alloys richer in lead are said to be more resistant than alloys with a smaller content of lead, Pohl giving an alloy of 5 parts tin and 12 parts lead, and Phlo one of 4 parts tin and 9 parts lead, hence almost identical with Pohl's.

Knapp has investigated lead-tin alloys with the following results: Three alloys of different composition were prepared:

A. 30.8 parts tin and 69.2 parts lead (the above-mentioned alloy of Phlo).

B. 21 parts tin and 79 parts lead (corresponding to the formula $SnPb_2$).

C. 80 parts tin and 20 parts lead.

Toward distilled water with the access of air the alloy A showed the greatest resistance, while from A and B a comparatively large quantity of oxide of lead (consisting of lead, carbonic acid and water) was separated.

Cold vinegar dissolved in the course of seven days per 15.5 square inches surface:

	Lead, gramme.	Tin, gramme.	Total, gramme.
From alloy A	0.0677	0.0267	0.0944
From alloy B	0.0773	0.0159	0.0932
From alloy C	0.0027	0.0337	0.0364

Hence the alloy richest in tin showed the greatest resistance toward the action of cold vinegar, while the alloy of Phlo proved no more resistant than the alloy with 79 parts lead. While for the same quantity of tin the alloy A contains about 9 times as much lead as C, it yields to vinegar 26 times as much lead.

Boiling vinegar dissolved in the course of one hour

	Lead, gramme.	Tin, gramme.	Total, gramme.
From alloy A	0.0130	0.0032	0.0162
From alloy B	0.0118	0.0055	0.0173
From alloy C	0.0058	0.0100	0.0158

The difference in the resistant power of the alloy richer in tin as compared with the two others is, therefore, considerably diminished by boiling and, by taking into consideration the total quantity of metal dissolved, Phlo's alloy proves nearly as resistant as the alloy richer in tin, the amount of lead dissolved being, however, nearly double. By taking into consideration the short time of action, it will be seen that the effect of the acid is considerably increased by the higher temperature.

Cold common salt solution with about 3.5 per cent. common salt, dissolved in the course of seven days from all three alloys only lead, no tin being dissolved. The amount of lead per 15.5 square inches surface was:

From the alloy A .....0.0023 gramme.
From the alloy B .....trace.
From the alloy C .....0.0499 gramme.

In this case the alloy poorest in lead loses the greatest quantity of it.

At a boiling heat the same common salt solution in the course of one hour also dissolved tin, the amount per $15\frac{1}{2}$ square inches surface being:

	Lead, gramme.	Tin, gramme.	Total, gramme.
From the alloy A	0.0078	0.0022	0.0100
From the alloy B	0.0080	0.0012	0.0092
From the alloy C	0.0036	0.0020	0.0056

In this case the alloy richest in tin suffers the smallest total loss in metal, but in proportion to its content of lead, a comparatively large amount of the latter is dissolved.

The results of these experiments show the extent to which the resisting power of one and the same alloy is dependent upon the nature of the influences to which it is exposed and the temperature at which they act.

R. Weber has made quite a number of experiments with lead-tin alloys in regard to their behavior towards vinegar. His investigations show that generally speaking the alloys are the more strongly attacked the greater their content of lead, no exception from this rule for some alloys richer in lead, as supposed by Pohl and Phlo, having been found. Further, a content of antimony does not prevent the alloy from being attacked, and that when vinegar is mixed with ¼ its volume of tartaric acid, the quantity of metal dissolved is increased fourfold.

In Germany, by law, vessels intended for measuring fluids must not contain more than 1 part lead to 5 parts tin.

CHAPTER V.

PREPARATION OF ALLOYS IN GENERAL.

Alloys are generally prepared by directly melting together the metals which are to take part in the mixture. At the first glance this would seem a very simple affair, requiring scarcely any explanation, but in fact great skill and judgment are necessary for the successful accomplishment of the object. Some alloys are in fact very difficult to prepare, and require special precautionary measures.

For melting purposes various kinds of utensils are employed. An iron kettle may be used for the manufacture of alloys with low melting temperatures, especially those of lead and tin, or alloys of these metals with antimony. For heating the kettle ordinary fuel or, when working on a small scale, illuminating gas may be used.

For alloys with higher melting temperatures crucibles are used in place of a kettle. Crucibles are more expensive and require frequent renewal, but they are indispensable for melting alloys with higher melting temperatures, for instance, the alloys of copper, nickel, silver, gold. In most cases crucibles are made of fire-clay mixed with graphite. The latter improves the refractory quality, prevents the crucible from cracking in burning it, and impedes the passage of oxidizing fire-gases through the red-hot walls of the crucible. The crucibles are generally heated in a furnace, coke being used as fuel. They are, as a rule, taken from the furnace by means of tongs and emptied by tilting. In doing this there is, however, danger of the crucible breaking, this danger increasing with the weight of the crucible, and therefore the capacity of the latter is generally limited to about 100 lbs. Hence if larger quantities are to be

melted, several crucibles have to be used and their contents combined after melting. This method has, however, several drawbacks. To overcome these, furnaces have been introduced in which the crucible is stationary and for the purpose of emptying it, the entire furnace is tilted over by means of a mechanical appliance. The crucible of such a furnace has a capacity of up to 1000 lbs.

When working on a large scale, the crucibles are sometimes placed upon the flat hearth of a furnace where they are heated by the passing flame of the fuel. The crucibles are emptied, as previously mentioned by means of tongs.

If, however, considerable quantities are at one time to be melted, and damage to the quality of the alloys from coming in contact with the gases of combustion need not be feared, a reverberatory furnace is used. The metal is placed upon the trough-shaped hearth of the furnace and directly melted by the passing flame. The melted metal is drawn off through the tap-hole. This process is generally employed in bronze foundries when bells and other large articles are to be cast. Wood is preferably used as fuel, since the content of sulphur in coal might pass from the gases into the metal and impair its quality. In many works gas is now used for heating the furnace. Special precautions must be taken to keep up a deoxidizing flame within the furnace. A small portion of the heat, which otherwise could be used for melting the metals, is sometimes lost thereby; but the great advantage is gained that as long as the gases of combustion passing over the metals absorb oxygen, the melting metals will actually remain in a metallic state. This is especially of great importance with metals which readily oxidize when exposed in a fused state to the action of the air. It may here be remarked that the oxides formed by careless work from the metals seldom take part in the formation of the alloy, so that even if the quantities of metals have been accurately weighed, the resulting alloy will not show the desired composition, since

the portion of the metals converted into oxide does not enter into the alloy.

For preparing alloys on a smaller scale in a crucible, special precautionary measures must be taken against oxidation of the metals. For this purpose the surface of the metals is covered with bodies which prevent the access of air, without, however, exerting any influence whatever, or at least only to a very small extent, upon the metals. In many cases anhydrous borax is used; but independently of the fact that borax is rather expensive and unnecessarily increases the cost of the alloys, its employment is accompanied by many evils. It is well known that in borax a portion of the boric acid is not perfectly saturated, and that in melting borax with base metals a certain portion of the acid is always absorbed, which with the sodium borate forms double salts of a glassy nature. Hence by fusing metals under borax a certain portion of them will be lost by forming a combination with the borax.

Glass consists of a mixture of silicates, and forms, when thrown upon fusing metal, a coating which completely excludes the access of air to the surface of the metal. Though it has also the property of absorbing certain metals when brought in contact with them in a liquid state, the influence it exerts upon alloys is, generally speaking, much less than that of an equal quantity of borax. If the metals to be fused together are such that a combination with carbon need not be feared, the fusing mass can also be protected from the influence of the oxygen of the atmosphere by covering it with a layer of pulverized charcoal. Many manufacturers are in the habit of throwing a certain quantity of fat upon the heated metal before fusion. The fat on being suddenly strongly heated decomposes and evolves a considerable quantity of gas, which exerts a protecting influence upon the surface of the metals. After the evolution of gas has ceased, there remains a very finely divided carbon which protects the metals from oxidation.

For the preparation of alloys from noble or costly metals it is recommended to effect the fusion in crucibles of graphite or of graphite mixed with clay, as the metal readily and completely separates from such crucibles. In regard to graphite crucibles we would draw attention to a circumstance, which, though unimportant in itself, may become very disagreeable in preparing alloys from costly metals. It sometimes happens that a graphite crucible a short time after being placed in the furnace bursts with a loud report, and the metals contained in it fall into the fire, from which they have to be rescued with considerable trouble. This phenomenon in most cases is due to faulty work in the making of the crucible. If for instance the mass of the crucible contains a small bubble filled with air or moisture, these bodies will expand strongly on heating, and this expansion may go so far as to cause the bursting of the crucible. But, as this defect cannot be recognized from the appearance of the crucible, it is recommended to test every crucible before using it for melting metals. This is done by putting them in a place where they gradually become strongly heated. Bad crucibles crack in most cases, and the others are sufficiently dried out so that they can be used for melting the metals without fear of cracking.

In preparing alloys the metal most difficult to fuse should be first melted, and the more fusible ones only introduced after the complete fusion of the first. The varying densities of the metals to be combined frequently render the formation of a homogeneous mass very difficult. Moreover, in many alloys certain chemical combinations are readily formed, while the rest of the metals form alloys, the preparation of which was not intended.

If two metals with greatly varying densities are alloyed and the mass is allowed to be quiescent, it will be observed that, after cooling and taking from the crucible, it shows clearly perceptible layers varying in color and appearance. By chemically examining these layers it will be found that

each of them contains different quantities of the metals used in alloying. To obtain in such case as homogeneous an alloy as possible, the metals, while in a state of fusion, must not be allowed to remain quiescent, but an intimate mixture be effected by vigorous stirring, sticks of dry soft wood being in many cases used for this purpose. By stirring the fused mass with one of these sticks, the wood is more or less carbonized according to the temperature of the mass. In consequence of the destructive distillation of the wood taking place thereby, there is evolved an abundance of gases which, by ascending in the fused mass, contribute to its intimate mixture, The stirring should be continued for some time and the alloy then cooled as rapidly as possible.

The production of proportionate solutions of the metals one in another in melting can sometimes be promoted by certain manipulations. To these belong, for instance, the process of allowing the alloy to cool and then remelting it. In casting articles scraps and waste generally result, which in order to be utilized have to be remelted. So-called old metal consisting of articles which have become useless by having been broken or otherwise damaged are also frequently remelted. The above-mentioned effect of remelting accounts for the fact that a moderate addition of such scraps, provided they consist of the same alloy, may be beneficial as regards the properties of the alloy to be melted. However, the metals chiefly used for alloying are quite readily oxidizable in the melting temperature, and many of them possess the property of dissolving their own oxides whereby their usefulness may be impaired. Now the more frequently the alloy is remelted, the more ample the opportunity for the absorption of oxides will be. From this it will be seen that the melting of old metal without the addition of fresh metal is only possible without producing an injurious effect when no oxides are absorbed during melting. No rule can be laid down regarding the propor-

tion of old to new metal most suitable for the production of serviceable alloys, since the old metal has, as a rule, been more or less often remelted.

When larger quantities of one metal are to be alloyed with smaller quantities of another, it is advisable to first melt together approximately equal quantities by weight of the two metals, and by a second melting combine the resulting alloy with the remainder of the metal. This method is frequently employed when there is considerable difference between the melting temperatures of the metals. If, for instance, a small amount of copper is to be alloyed with a large quantity of tin, an alloy, the melting temperature of which will be considerably lower than that of copper, is first made by melting the copper together with about the same quantity by weight of tin, and then adding to this the remaining tin. The same method is adopted when three or more metals of different melting points are to be alloyed in varying proportions by weight. To make, for instance, an alloy from 3 parts lead (melting point 618.8° F.), 1 part tin (melting point 446° F.), and 1 part antimony, (melting point 1166° F.), the most suitable process is to first alloy one-third, *i. e.* 1 part, of the lead with the entire quantity of antimony by dissolving the latter in the lead after it has been melted, then adding the rest of the lead and finally combining with this lead-antimony alloy the tin which is most readily liquified, and being also the most expensive of the three metals, its oxidation should as much as possible be prevented. The same object might also be accomplished by alloying one part of the lead, as previously described, with the antimony, another part of the lead, or under circumstances the entire remainder of it, with the tin, and then combining the lead-antimony alloy with the lead-tin alloy.

When a larger amount of copper (melting point 1983.2° F.) is to be alloyed with smaller quantities of nickel (melting point 2732° F.) and zinc (melting point 779° F.), one

part of the copper may first be melted together with the nickel and another part with the zinc, finally combining the nickel-copper alloy with the zinc-copper alloy. The reason for this apparently more troublesome process may be found in the fact that, on the one hand, uniform combination is facilitated by the formation of intermediate alloys with melting points less far apart than those of the constituent metals, and, furthermore, that readily oxidizable or volatile metals, for instance, zinc, are less subject to oxidization or volatilization when alloyed than when in a pure state.

While formerly only a few alloys were known, a large number are at present used in the industries, and we find very rare metals sometimes employed for the preparation of alloys to impart special properties. One of the principal causes of this advance in the industry is the progress of mechanics. We need only to consider the bearings of shafts and axles in order to understand the varying demands made by the engineer as regards the properties of alloys. How different must be the nature of an alloy which serves for the construction of the bearing of an axle revolving with a light load perhaps once in a second, from that which has to bear a heavily-loaded shaft making many hundred revolutions per minute! For many purposes alloys possessing great ductility are required, for others the chief requisite is hardness, others again must have a high degree of elasticity, and still others as low a melting point as possible. It will be readily understood that these different demands can only be satisfied by adding to the alloys suitable quantities of metals of varying properties.

Though most heavy metals are at the present time used in the manufacture of alloys, copper, tin, zinc, lead, silver and gold are more frequently employed than others, the alloys of these metals being at the same time those which have been longest known and used. In modern times the alloys prepared with the assistance of nickel have also become of great importance, as well as those of which aluminium and vanadium form a constituent.

Everyone who pays close attention to the subject of alloys knows that the amount of information which has been gained upon this important branch of metallurgy is comparatively meagre, and that much is still to be expected from the progress of chemistry. The metallurgist, if left to himself, cannot be expected to arrive at certain results, because, probably, he may be wanting in chemical knowledge or in the methodical course of investigation which must be possessed by those who are qualified to successfully prosecute such researches. These qualifications are so much the more indispensable when it is remembered that every new alloy, by the fact of its properties being different from those of its constituents, may be regarded as a new metal. Before proceeding with the description of the most important alloys, it may be convenient to say a few words about the best methods of making experiments in the preparation of new alloys.

It is known that the elements always combine with one another in certain quantities by weight, which are termed atomic weights. (A table of the atomic weights of the principal metals is found upon page 22.) By mixing the metals according to equivalent quantities, alloys of determined characteristic properties are, as a rule, obtained. If these properties do not answer the demands made of the alloy, the object is frequently attained by taking two, three, or more equivalents of one metal. An exception to this rule is only made in certain cases, and especially where, according to experience, a very small quantity of a metal suffices considerably to change the properties of the alloy. It is then most suitable to prepare the mixtures serving for the experiment according to thousandths, and with every new experiment change the proportion between the separate metals a certain number of thousandths.

For combining metals with non-metallic elements, for instance with sulphur or with phosphorus, it is, however, not sufficient to choose the proportions according to thou-

sandths, it being necessary to add these bodies according to ten thousandths. For these elements the form in which they are used is also of importance, which, however, will be referred to in speaking of them later on. It may here be remarked that the application of the term alloy to such metals which, so to say, are contaminated by phosphorus or sulphur, is entirely incorrect. It is used, however, for want of a better one, since it at least indicates that we are not dealing with a pure metal.

CHAPTER VI.

COPPER ALLOYS.

PURE copper by reason of its great ductility and tenacity forms a very important and valuable material for various applications in the arts, but its employment for many purposes is connected with difficulties. It is, as previously mentioned, but seldom used in the foundry on account of its tendency to develop gases in casting whereby it swells up, and sound, strong castings can only be obtained with great difficulty, even if the work is done with the greatest care. However certain alloys of copper possess, in addition to the valuable properties of the latter, others which render them especially suitable for certain industrial purposes, and moreover, it is possible to impart to such alloys the most desirable properties, as they can be made soft or very hard; brittle or elastic, malleable or non-malleable, etc.

The production of copper alloys is attended with certain difficulties, since this metal has a very high melting point and the presence of very small qnantities of foreign bodies exerts a great influence upon its own properties as well as upon those of its alloys.

Thus a content of $\frac{1}{1000}$ to $\frac{3}{1000}$ of lead somewhat increases the ductility of copper to be rolled; but the presence of one full thousandth of lead renders the metal unfit for the preparation of brass which is to be rolled into sheets or drawn out into wire. By adding to copper up to $\frac{3}{1000}$ of lead, it acquires the property of being red-short or hot-short, and by increasing the content of lead to one per cent. it becomes entirely useless, it being both red-short and cold-short. A content of lead always exerts an injurious influence upon the properties of copper, this influence

being more strongly observed at a higher temperature than at an ordinary one.

A content of iron exceeding $\frac{3}{1000}$ has also an injurious effect upon the properties of copper, rendering it hard and brittle. Small quantities of nickel affect copper injuriously in making it less malleable, the evil being still further increased if besides this metal a small quantity of antimony be present. Antimony and arsenic by themselves mixed with copper considerably decrease its highly-valued property of ductility. Copper containing only $\frac{1}{1000}$ of antimony can no longer be worked for sheet brass. Bismuth acts in a manner similar to antimony. Zinc mixed with copper up to $\frac{6}{1000}$ makes it red-short. Certain alloys of copper and zinc can, however, be well worked, the most important of such alloys being brass. A content of tin and silver seems not to have an injurious effect upon the properties of copper, and these two metals, if added in certain proportions, yield alloys which are distinguished by special valuable properties.

An admixture of cuprous oxide makes copper both red-short and cold-short, especially if present in larger quantities, and further imparts to it the disagreeable property of considerably contracting in casting. Moreover, the castings from such copper show an unequal density, so that plates of it cannot be used for copper-plate printing. It may here be remarked that most brands of copper found in commerce contain certain quantities of cuprous oxide, it being claimed that an admixture of one-half to two per cent. of it is even beneficial, as it counteracts the injurious influence of foreign metals upon the copper.

Beside the above-mentioned metals, many brands of copper found in commerce frequently contain bodies belonging to the non-metals, such as sulphur, silicon, and phosphorus. The influence of these bodies is, as a rule, very injurious.

A content of sulphur makes the copper red-short and

castings of it blown. By a content of silicon the copper loses its pure red color and acquires one shading into white, its ductility being at the same time considerably affected. Copper containing nearly two per cent. of silicon can only be rolled in the cold, as it cracks in the heat. With a still greater content of silicon the copper becomes a yellowish-white metal of extraordinary brittleness, so that it can no longer be worked to advantage.

A content of phosphorus exerts a considerable influence upon the properties of copper, generally increasing its hardness and at the same time making it more fusible. With an admixture of $\frac{1}{1000}$ of phosphorus the copper can only be rolled in the cold, while with a still greater content it becomes brittle in the cold. Some alloys of copper with phosphorus, known as phosphor-bronze, are, however, used for certain industrial purposes on account of their special properties, they being distinguished by particular strength, ductility, and beautiful color. These combinations will be referred to later on.

According to the more recent researches by Hampe, copper shows the following behavior towards admixtures:—

With a content of between $\frac{2}{1000}$ and $\frac{22}{1000}$ of cuprous oxide, the properties of the copper are not sensibly affected, it becoming red-short only in the presence of $\frac{67}{1000}$; and a content of this compound always acts in such a manner as to increase the brittleness of the metal more in the cold than in the heat. One-thousandth of arsenic exerts no influence upon the copper, but $\frac{20}{1000}$ of it render it cold-short and hard. It only becomes red-short with $\frac{10}{1000}$ of arsenic, but is not cold-short, which is contrary to the opinions formerly held in regard to the influence of arsenic upon copper. Antimony acts similarly to arsenic, except that a smaller quantity of it will make the copper red-short.

A content of one and a half thousandths of lead exerts no influence upon the properties of copper; a slight brittleness in the heat shows itself, however, with a content of $\frac{3}{1000}$

which becomes greater with one of $\frac{4}{1000}$, and is clearly perceptible in the cold.

According to these more recent researches a content of bismuth exerts an especially injurious influence upon the properties of copper, an indefinitely small quantity sufficing to decrease the ductility in the heat, while with a content of $\frac{5}{1000}$ the copper becomes exceedingly red-short and sensibly cold-short.

A considerable portion of the copper occurring in commerce is extracted from minerals containing a number of other metals, this holding especially good in regard to those brands obtained from gray copper ore or fahl ore.* Experts can tell from the external properties of the metal, especially by the color, fracture, and ductility, whether it is suitable for certain purposes or not. But it is, of course, impossible to recognize in this manner the quantities of foreign bodies. In buying a large lot of copper for alloys it is therefore recommended to subject it to an accurate chemical analysis, in order to be sure that it is free from lead and bismuth, which are especially injurious.

As previously mentioned, the number of copper alloys is very large, the most important being those with tin, zinc, nickel, gold, silver, platinum, and mercury, and further, with aluminium; the alloys of copper with lead, antimony, and iron are less frequently used.

After giving a brief introductory sketch of the alloys of copper with the precious metals, which have been used from very remote times, we shall first speak of the alloys of copper with the base metals, they being of special interest for industrial purposes, and, besides, presenting more technical difficulties in their preparation.

Copper-gold alloys.—Gold, as previously mentioned having but a slight degree of hardness, must be alloyed with other metals in order to prevent its wearing too rapidly,

* It contains copper, antimony, arsenic, and sulphur.

copper and silver, either by themselves or together, being generally used for the purpose. Beside the fact that the gold alloys show a greater degree of hardness than the pure metal, the color of the latter is also changed by alloying with silver or copper, there being gold with a color shading into white (alloyed with silver) and other varieties shading into red (alloyed with copper). There is also a green gold, which is an alloy of gold, silver, and copper.

According to the purpose for which gold alloys are to be used, they are prepared either with copper or silver alone, or with the assistance of both metals. The gold coins of Europe consist always of an alloy of gold with copper, a content of silver, which must, however, be very small, being due to the use of argentiferous gold. The preparation of alloys of gold and of silver has become very extensive on account of their being used for coinage and articles of jewelry, and will be referred to later on.

Copper-silver alloys,—The alloys of copper with silver are extensively used for coinage and silverware. As may be seen from the properties of both metals, these alloys possess a considerable degree of ductility, and if the proportions in which the metals are mixed are so chosen that the copper slightly predominates, their properties are almost exactly a mean between those of the two metals. They will be fully discussed later on, and we only mention here that most alloys of silver and copper contain more of the former than of the latter metal.

The alloys of the other noble metals, especially those of the platinum group, find but a limited application in the industries; they will be referred to latter on.

Alloys of copper with the base metals.—Although the number of alloys of copper with the base metals is very large, those known under the general terms of brass and bronze are so extensively used in the various industries as to make most of the others appear unimportant in comparison. Bronze has been known from very remote times, and

was used by the ancients in casting statues and other ornaments. The bronze used by the prehistoric nations contained no lead, and came nearest to what is at the present time designated by the term bronze, *i. e.*, an alloy of copper and tin. The bronze used by the Romans and post-Romans was rarely an alloy of pure copper and tin, but contained usually more or less lead.

Brass, the other important alloy of copper mentioned above, was manufactured by cementing sheets of copper with calamine or carbonate of zinc long before zinc in a metallic form was known.

COPPER-ZINC ALLOYS.

The compounds under this heading comprise *brass, tombac, and allied* alloys which contain copper and zinc as chief constituents. The first account of the alloy of copper and zinc transmitted to the present times was written by Aristotle, who states that a people who inhabited a country adjoining the Euxine Sea prepared their copper of a beautiful white color by mixing and cementing it with an earth found there, and not with tin, as was apparently the custom. Strabo also alludes to the preparation of the alloy of copper and zinc by the Phrygians from the calcination of certain earths found in the neighborhood of Andêra, and other authors, in the time of Augustus, speak distinctly of cadmia and its property of converting copper into *aurichalcum*, under which title the zinc alloy was subsequently known. Several writers of the Christian era who have referred to this compound are not more explicit than their predecessors; still it is evident, from various recent analyses of old alloys, that zinc was contained in many of those prepared about the commencement of the present era.

The influence of zinc upon copper has several times been previously referred to. It renders copper fit for casting, and the copper-zinc alloys do not show the strong tendency towards liquation peculiar to copper-tin alloys. According

to Charpy,* copper-zinc alloys with a content of up to 33 per cent. consist of an aggregation of dendritic (fir-tree-like) crystallites which form solidified solutions of the copper and zinc (mixed crystals of the two constituents) without liquation or disintegration, as is the case with eutectic alloys, having previously taken place. In alloys with 33 to 45 per cent. zinc, crystallites are noticed which are surrounded by a mass, probably of the combination $CuZn_2$, consisting of fine crystals. In alloys richer in zinc two different constituents can also be recognized.

The strength and hardness of copper are, to be sure, increased to a less extent by zinc than by tin, but its flexibility is far less decreased by it, so that, while copper-tin alloys with a content of about 6 per cent. tin can no longer be worked at the ordinary temperature, copper-zinc alloys with even 50 per cent. zinc can with care be worked at the ordinary temperature, provided they do not contain other bodies which impair their flexibility. If, however, the content of zinc exceeds 50 per cent. the alloy becomes rapidly brittle.

On the other hand, many copper-zinc alloys cannot be worked so well at a red heat as some copper-tin alloys; only a few with a fixed content of zinc stand working in a heated state, and are malleable. Hence copper-zinc alloys are, as a rule, worked cold by hammering, pressing, rolling, drawing, etc., and this property of standing such manipulations without previous heating, is without doubt an advantage. However, like most metals worked cold, they become by these manipulations hard and brittle, and occasional annealing is, as a rule, required to restore to them their lost flexibility.

BRASS, ITS PROPERTIES, MANUFACTURE, AND USES.

The manufacture of brass was introduced, in 1550, in

*G. Charpy. "Etudes microscopiques des alliages metalliques." Bulletin de la Société d' Encouragement. 1907.

Germany by Erasmus Ebener, an artist of Nürnberg, who prepared it by fusing copper with so-called *tutia fornacem* or furnace cadmia. In England the first brass by the direct admixture of copper and spelter, with or without the inclusion of calamine, was made in 1781, by James Emerson, who took out a patent for the process.

Brass, generally speaking, should contain only copper and zinc, but most varieties found in commerce contain small quantities of iron, tin, arsenic, and lead. In many cases these admixtures are due to contaminations mixed with the ores from which the copper or zinc is extracted, while in others they have been intentionally added in order to change the ductility, fusibility, etc., of the alloy. Copper and zinc can be mixed together within very wide limits, the resulting alloys being always serviceable. Generally speaking, it may be said that with an increase in the content of copper the color inclines more towards a golden, the malleability and softness of the alloy being increased at the same time. With an increase in the content of zinc the color becomes lighter and lighter, and finally shades into a grayish-white, while the alloys become more fusible, brittle, and at the same time harder. Just as different as the properties of the respective alloys is also the cost of production, the price of brass increasing with the greater content of copper. Very extensive researches have been made in regard to the behavior of alloys of copper and zinc, which may be briefly expressed as follows:—An alloy containing from 1 to 7 per cent. of zinc still shows the color of copper, or at the utmost only a slight yellow tinge. With 7.4 to 13.8 per cent of zinc, the color of the alloy undergoes a considerable change, it being a pleasant red-yellow. With from 13.8 to 16.6 per cent. the color may be designated a pure yellow, while that of alloys containing up to 30 per cent. of zinc is also yellow, but not pure. It is a singular fact that with a content of over 30 per cent. of zinc a red color appears again, which is most pronounced

with equal parts by weight of the metals, an alloy of 50 parts of copper and 50 of zinc having almost a golden color, but exhibiting also a high degree of brittleness. With a still higher content of zinc the gold color rapidly decreases, becoming reddish-white with 53 per cent., yellowish-white with 56 per cent., and bluish-white with 64 per cent.; with a still higher content of zinc the alloy acquires a lead color.

The physical properties of alloys of copper and zinc differ very much according to the quantities of copper and zinc contained in them. Alloys containing up to 35 per cent. of zinc can be converted into wire or sheet, in the cold only, those with from 15 to 20 per cent. being the most ductile.

Alloys with from 36 to 40 per cent. of zinc can be worked in the cold as well as in the heat. With a still higher content the ductility decreases rapidly, and an alloy with, for instance, from 60 to 70 per cent. of zinc is so brittle that it cannot be worked. If, however, the content of zinc is increased up to a maximum (70 to 90 per cent.), the ductility increases again and the alloy can be worked quite well in the heat; but not at red heat.

Brass shows always a crystalline structure, which is the more pronounced the more brittle the alloy is, and hence that prepared from equal parts of copper and zinc shows the most distinct crystalline structure.

In connection with this some researches in regard to metals becoming crystalline, made by S. Kalischer, may be of interest. By heating rolled zinc to from 302° to 338° F., it suffers a series of permanent changes without its external appearance being directly altered. It loses its clear sound and becomes almost without sound, like lead. It can be more readily bent, but breaks more easily, and in bending emits a noise similar to the "cry of tin." All these alterations are due to a change in the molecular structure of the zinc, it becoming crystalline. This crys-

tallization can be readily rendered perceptible by dipping a heated strip of zinc into a solution of sulphate of copper, the copper, which is immediately precipitated, showing clearly perceptible crystallization. The fracture of the rolled and heated zinc is also crystalline. To avoid this change it is recommended not to exceed a temperature of 266° F. in manufacturing sheet-zinc. Sheets of cadmium and of tin become crystalline at about 392° F. Sheet-iron and sheet-copper are also crystalline, but sheet-steel is not. Kalischer examined four varieties of sheet-brass constituted as follows:

	Parts.			
	I.	II.	III.	IV.
Copper	66	62.5	60	56.8
Zinc	34	37.5	40	43.2

Samples Nos. I. and II. were undoubtedly crystalline, and sample No. III. showed traces of crystallization, while No. IV. did not become crystalline even by heating.

Sheets of tombac composed of—

	Parts.		
	I.	II.	III.
Copper	73.74	80.38	90.09
Zinc	25.96	19.29	9.91
Tin	0.30	0.33	—

were all crystalline. No crystallization could be observed in bronze-sheets composed of—

	Parts.	
	I.	II.
Copper	90	88.23
Zinc	5	8.82
Tin	5	2.95

Rolled lead is crystalline, but rolled fine silver and gold are not. By reason of these observations and experiments,

Kalischer is of the opinion that the crystalline state is natural to most metals, but they can be deprived of it by mechanical influences, and many can be reconverted into it under the influence of heat.

If a very ductile brass is to be prepared, great care must be had to use metals of the utmost purity, since exceedingly small admixtures of foreign metals suffice to injure considerably the ductility, rendering the fabrication of very thin sheets or fine wire impossible.

The strength of brass, as shown by many experiments, is also intimately connected with its composition, that containing about 28.5 per cent. of zinc showing the greatest absolute strength. The strength depends, however, to a considerable extent, also on the mechanical treatment the metal has received. A piece of brass of 0.001 square inch breaks with the following loads:—

Cast brass	breaks with	2777.5	pounds.
Ordinary wire	"	7293	"
Hard-drawn thin wire	"	9080.5	"
Annealed thin wire	"	7100 to 8628	"

The molecular structure of brass can be much changed by treatment, it becoming more brittle by continuous manipulation, so that in drawing wire it must be frequently annealed to prevent it from becoming brittle. If brass is strongly heated and rapidly cooled, its hardness decreases, its behavior in this respect being opposite to that of steel. Brass which, for instance, as a constituent of machines, is subjected to repeated shocks, becomes brittle and fragile.

A very important factor in brass is its melting point, there being wide deviations in this respect, which are readily explained by the great difference in the melting points of the two constituent metals. Generally speaking, the fusing point of brass lies at about 1832° F. If brass in a fused state is kept for some time in contact with air, its composition undergoes an essential change by the com-

bustion of the greater portion of the zinc contained in it, which explains the change of color frequently observed in brass fused for some time in contact with air.

Old copper derived from worn-out copper articles is frequently used in the manufacture of brass. Such copper contains, however, generally foreign metals in the shape of solder, etc., which may exert either a favorable or an injurious influence upon the properties of the brass. Lead, tin, and iron are the most frequently occuring contaminations. If the brass is to be used for castings, their injurious influence is not so great as in the manufacture of thin sheet or wire. To brass intended for castings up to two per cent. of lead is frequently added, such addition making the alloy somewhat harder, and depriving it at the same time of the disagreeable property of fouling the tools in working, which is of special importance in filing and turning. In casting brass containing lead care must, however, be had to cool the castings very rapidly, as otherwise the lead readily separates in the lower portion of the casting and produces unsightly spots.

By a slight addition of tin the brass becomes more fusible, somewhat denser, and takes a better polish; it is also rendered somewhat less brittle. The presence of a small quantity of iron increases the hardness of brass considerably, such brass on exposure to the air being, however, easily stained by rust.

In the arts brass is commonly employed in the construction of scientific apparatus, mathematical instruments, small parts of machinery, and for many other purposes. A distinction is generally made between sheet brass used in the manufacture of wire and sheets, and cast-brass, which requires no further mechanical manipulation than turning and filing. A number of alloys occur in commerce under various names, but, as regards their composition, they must be included in the generic term, *brass*, though some of them are especially adapted for certain purposes.

The table given below shows the manner in which the properties of the finished alloy are affected by its composition. In the column "cohesion" is given the weight in tons required for breaking a bar of one square centimeter. The minimum of hardness and fusibility is denoted by 1.

Number.	Composition of the alloys according to		Properties of the alloys.						
	Equivalents Cu:Zn.	Per cent. Cu.	Specific gravity.	Color.	Fracture.	Cohesion.	Ductility at 59° F.	Hardness.	Fusibility.
1	1:0	100	8.667	red	—	24.6	8	22	15
2	10:1	90.72	8.505	reddish-yellow	coarse-grained	12.1	6	21	14
3	9:1	89.80	8.607	"	"	11.5	4	20	13
4	8:1	88.60	8.633	"	"	12.8	2	19	12
5	7:1	87.30	8.587	"	"	13.2	5	18	11
6	6:1	85.40	8.591	yellowish-red	fine-fibrous	14.1	5	17	10
7	5:1	83.02	8.415	"	"	13.7	11	16	9
8	4:1	79.65	8.448	"	"	14.7	7	15	8
9	3:1	74.58	8.397	pale yellow	"	13.1	10	14	7
10	2:1	66.18	8.299	vivid yellow	"	12.5	3	13	6
11	1:1	49.47	8.330	"	coarse-grained	9.2	12	12	6
12	1:2	32.85	8.263	dark yellow	"	19.3	1	10	6
13	8:17	31.52	7.721	silver-white	conchoidal	2.1	—	5	5
14	8:18	30.36	7.836	"	"	2.2	very brittle	6	5
15	8:19	29.17	7.019	pale gray	"	0.7	—	7	5
16	8:20	28.12	7.603	ash gray	vitreous	3.2	brittle	3	5
17	8:21	27.10	7.058	pale gray	conchoidal	0.9	—	9	5
18	8:22	26.24	7.882	"	"	0.8	very brittle	8	5
19	8:23	25.39	7.443	ash gray	fine-grained	5.9	slightly ductile	1	5
20	1:3	24.50	7.449	"	"	3.1	very brittle	2	4
21	1:4	19.65	7.371	"	"	1.9	brittle	4	3
22	1:5	16.36	6.605	dark gray	"	1.8	"	11	2
23	0:1	0.	6.895	pale gray	—	15.2	"	20	1

Sheet brass (for the manufacture of sheet and wire). Especially pure metals, as free as possible from foreign bodies injurious to ductility (bismuth, antimony, arsenic, tin, lead, iron) have to be used for this purpose. Sheet to be stretched very thin under the hammer, for instance, the best quality of German sheet-brass for musical instruments contains, as a rule, 19 to 21 per cent. zinc, sheet still suitable for most purposes, 22 to 30 per cent., and sheet for toys and articles easily shaped 30 to 40 per cent. Brass for wire requires similar composition.

For the purpose of investigating the influence of antimony upon the cold-shortness of brass, E. S. Sperry prepared brass plates of the best quality of Lake copper and

refined zinc with varying quantities of antimony and tested their behavior in rolling and by the condition of their fractures. The hardest alloy of 60 per cent. copper and 40 per cent. zinc was selected so that the influence of the addition of antimony should be more apparent. The additions of antimony amounted to 0.01, 0.02, 0.05, 0.1, and 0.65 per cent. While Kerl states that 0.001 per cent. of antimony in copper renders the brass unfit for wire and sheet, Sperry found that brass with 0.006 per cent.—hence from copper with 0.01 per cent.—antimony could be satisfactorily rolled; with softer alloys the influence of the same quantity of antimony is said to be still less injurious. A content of 0.02 per cent. antimony could be readily recognized by the condition of the fracture. Since some brands of electrolytic copper contain from 0.001 to 0.08 per cent. of antimony and are generally used for brass without being previously tested, the objections of some manufacturers to such copper are readily explained.

Filings and turnings always contain small quantities of iron particles and hence are not suitable as an addition to the better qualities of brass. Silesian zinc, as a rule, contains not less than 0.75 per cent. lead. Missouri zinc is very pure, and also Spanish zinc, brand R. C. A. Refinado, the latter being free from arsenic, antimony and sulphur, and contains only 0.05 per cent. lead and a trace of iron; it is used for the best quality of sheet-brass (cartridge shells). The more sheet-brass is to resist the action of acid and alkaline fluids, the richer in copper it should be, and accordingly, the following proportions of copper to zinc may be recommended: 70 : 30, 66 : 34, and 60 : 40. Brass for cartridge shells contains 72 parts copper and 28 parts zinc, with at the utmost 0.25 per cent. lead, or still better entirely free from lead.

The best evidence of the quality of a brand of copper is that it yields brass suitable for the preparation of thin sheet and wire, and the sharpest test for the quality of the cop-

per consists in that when the brass is drawn out to tubes over a corebar, the tubes show no cracks. The following analyses show the composition of different varieties of brass for sheet and wire.

Brass.	Place of derivation.	Copper.	Zinc.	Lead.	Tin.	Silicon.	Antimony.	Iron.
Sheet	Jemappes	64.6	33.7	1.4	0.2	—	—	—
"	Stolberg	64.8	32.8	2.0	0.4	—	—	—
"	Romilly	70.1	29.26	0.28	0.17	—	—	—
"	Rosthorn (Vienna)	68.1	31.9	trace	—	—	—	—
"	—	71.5	28.5	—	—	—	—	—
"	—	71.36	28.15	—	—	—	—	—
"	—	71.10	27.6	1.3	—	—	—	—
"	Iserlohn and Romilly	70.1	29.9	—	—	—	—	—
"	Lüdenscheid	72.73	27.27	—	—	—	—	—
"	—— (brittle)	63.66	33.02	2.52	—	0.61	—	—
"	Hegermühl	70.16	27.45	0.79	0.20	—	—	—
"	Oker	69.98	29.54	0.97	—	—	0.79	0.23
Wire	England	70.29	29.26	0.28	0.17	—	—	—
"	Augsburg	71.89	27.63	0.85	—	—	—	—
"	Neustadt-Eberswalde	70.16	27.45	0.20	0.79	—	—	—
"	—	71.36	28.15	—	—	—	—	—
"	—	71.5	28.5	—	—	—	—	—
"	—	71.0	27.6	—	—	—	—	—
"	(Good quality)	65.4	34.6	—	—	—	—	—
"	(Brittle)	65.5	32.4	2.1	—	—	—	—
	(Good composition for sheet and wire)	67	32	0.5	0.5	—	—	—
	China, best quality brass	10	5	—	—	—	—	—
	China, ordinary quality brass	10	2.7	—	—	—	—	—

Japanese brass (Schin-chiu) contains as a rule 30 parts zinc to 70 parts copper, though there are also alloys with 35 parts zinc.

Alloys with 34 to 37 and 40 per cent. zinc are frequently used for the manufacture of sheet and wire, sheet with 37 per cent. zinc being distinguished by extraordinary toughness and ductility in a cold state.

Cast-brass being used for the most diverse purposes, it is difficult to give a composition of general value, since the demands made on this metal vary much according to the article to be manufactured, it being used for very ordinary wares, such as locks, keys, shields, escutcheons, buttons, hinges, etc., as well as for the finest mechanical instruments and objects of art.

As a rule cast-brass contains more zinc than that which is to be worked into sheet and wire. It is therefore more

fusible, but at the same time harder and more brittle than wire-brass. The materials not being chosen with such great care as for wire, a chemical analysis reveals frequently the presence of a considerable number of foreign metals. The turnings, chips, and other brass waste are generally utilized by melting them together by themselves, or as addition in fusing cast-brass. As, besides brass, such waste frequently contains iron and bronze, the contamination of the cast-brass with iron, tin, and lead is readily accounted for; sometimes a small quantity of arsenic is also found. Cast-brass is also much used in the manufacture of the so-called hard solder for soldering articles exposed to a high temperature. In the following table we give an analysis of different kinds of cast-brass, which shows the great variations in its composition.

Variety.	Copper. Per cent.	Zinc. Per cent.	Iron. Per cent.	Lead. Per cent.	Tin. Per cent.
Cast brass from Oker.....	71.88	24.42	2.32	1.09	—
Cast brass from Oker.....	64.24	37.27	0.12	0.59	—
Black Forest clock wheels.	60.66	36.88	0.74	—	1.35
Black Forest clock wheels.	66.06	31.46	1.43	0.88	—
Cast brass from Iserlohn..	63.7	33.5	—	0.3	2.5
Cast brass from Iserlohn..	64.5	32.4	—	2.9	0.2
French yellow brass (*Potin jaune*)	71.9	24.9	—	2.0	1.2
English sterling metal....	66.2	33.11	0.66	2.0	—
English sterling metal....	66.66	26.66	0.66	—	—

Ordinary cast-brass (*potin jaune*, *potin gris*, *sterling metal*).—The mixture of metals known under these names is the poorest quality of brass, and its composition varies so much as to make it impossible to state it within narrow limits. This quality of brass is generally prepared by fusing together old brass-waste of all kinds and subjecting it to a casting test. If the fracture is not too coarse-grained and the metal not too brittle, it is used without further addition for articles known under the collective term of brazier's ware (spigots, candlesticks, mortars, etc.). Brass

of this quality is readily worked with the file, but difficult to turn.

By adding to ordinary cast-brass a certain quantity of lead and tin, a metal of a somewhat whiter color is obtained, which is called *potin gris* by the French, and is more easily worked with the lathe and file. The so-called "sterling metal" is somewhat harder in consequence of a content of iron, and can therefore be much better worked than ordinary brass. By adding to sterling metal some tin, it acquires still greater hardness and takes a good polish.

Fine cast-brass.—Brass to be suitable for the manufacture of fine articles must, besides being readily worked with file and chisel, possess other properties of great importance in the manufacture of such articles. It should allow of being readily cast and fill the moulds exactly. Further, articles of luxury manufactured from brass are frequently to be gilded, and experience has shown that brass of a beautiful color approaching that of gold requires less gold for the purpose than brass of an unsightly pale-yellow color. In order to be enabled to save gold, it is therefore of importance to manufacture the alloy so as to show a color shading into reddish. Generally speaking, such alloys contain from 20 to 50 parts of zinc to 100 parts of copper; lead or tin, or both, in the proportion of 0.25 to 3 per cent. of each metal being added, according to the purpose for which the alloy is to be used. In the following we give the compositions of several alloys which have stood a practical test in this respect.

Tough brass for tubes.—In chemical factories tubes and other utensils of brass are frequently used, which must be capable of resisting chemical influences as well as pressure. In preparing alloys for this purpose very pure materials should be employed. The following compositions may be recommended:

	I.	II.	III.	IV.
Copper	80	70	66	60
Zinc	20	30	34	40

Alloy No. I. is used chiefly in England; the other three are employed in German factories.

Hamilton's metal, mosaic gold, chrysorin.—The alloys known under the above names have a very beautiful color, closely resembling that of gold, and are distinguished by a very fine grain, which makes them especially suitable for the manufacture of castings to be subsequently gilded. The alloys are, as a rule, composed of copper, 100 parts; zinc, 50 to 55.

In order to obtain a thoroughly homogeneous mixture of the two metals it is recommended first to bring into the the crucible one-half of the zinc to be used; place upon this the copper, and fuse the mixture under a cover of borax at as low a temperature as possible. When the contents of the crucible are liquid, heat the other half of the zinc, previously cut in small pieces, until almost melted, and throw it into the crucible in portions; stir constantly, to effect as intimate a mixture of the metals as possible.

French cast-brass for fine castings.—As is well known, the bronze industry has reached a high degree of perfection in France, where clock-cases, statuettes, and other articles of luxury are manufactured on a large scale. The so-called bronze used for these articles is, however, in most cases not actual bronze, but fine cast-brass. In the following table we give the compositions of a few mixtures of metals generally used by the French manufacturers. They can be readily cast, worked with file or chisel, and easily gilded.

	Parts.			
	I.	II.	III.	IV.
Copper	63.70	64.45	70.90	72.43
Zinc	33.55	32.44	24.05	22.75
Tin	2.50	0.25	2.00	1.87
Lead	0.25	2.86	3.05	2.95

Bristol brass (*Prince's metal*).—The alloy known by this name possesses properties similar to those of the above-mentioned French varieties of brass, and can be prepared according to the following proportions:

	I.	II.	III.
Copper	75.7	67.2	60.8
Zinc	24.3	32.8	39.2

Regarding the preparation of this and similar alloys, the same holds good as has been said under Hamilton's metal.

Ronia metal consists of brass, with a small quantity of cobalt, manganese, and phosphorus.

D'Arcet's gilding metals have the following composition:

	I.	II.	III.	IV.
Copper	63.70	64.45	70.90	72.43
Zinc	33.55	32.44	24.05	22.75
Tin	2.50	0.25	2.00	1.87
Lead	0.25	2.86	3.05	2.95
Specific gravity	8.395	8.542	8.492	8.275

Malleable brass.—For castings which are to be shaped by forging or rolling, copper alloys rich in zinc (Muntz metal) and copper-zinc-iron alloys (Aich metal, sterro-metal, delta metal) are especially suitable, as they possess great strength, and the valuable property of being ductile in the cold as well as at a red heat. A content of 1 to 3 per cent. of iron is claimed to increase the malleability at a red heat. It is not yet decided whether the small content of iron produces these properties, or whether they are due to the absorption of the oxygen of the copper by the iron. By a larger addition of iron the ductility of the alloys is impaired. The observation that brass, which as ordinarily composed is brittle at a red heat, becomes ductile at that temperature when it contains not less than 35 per cent., and not more than, 45 per cent. of zinc, appears to have first been made by J. Keir of Westbromwich, near Birmingham, who, in 1779, took out a patent for a metallic mixture

of copper 54, zinc 40.5, and iron 5, which could be forged cold as well as at a red heat. This alloy was to be used for ship-sheathing, in the manufacture of nails and rivets coming in contact with sea-water, etc. The matter fell into oblivion, and in 1832 another Englishman, Muntz, took out a patent for an alloy of copper, 60 parts, and zinc, 40 parts, or copper 56, zinc 43¼, and lead 3¾, intended for the same purposes. This alloy became known as *Muntz metal* or *malleable brass*. It is still employed, chiefly for ship-sheathing, bolts and rivets, instead of copper, because it is claimed that the sea-water attacks the zinc gradually and uniformly over the entire surface, and that it prevents the deposit of barnacles, etc. According to the most recent investigations, this brass, however, is corroded not uniformly, but in holes.

To the malleable varieties of brass belong:

Malleable brass, Muntz metal, yellow metal, etc.—These alloys possess the valuable property of being ductile in the heat, and castings prepared from them can be worked warm like iron.

Yellow metal.—This metal possesses the property of being less attacked by sea-water than pure copper, and it was formerly much used for ship-sheathing and in the manufacture of nails and rivets coming in contact with sea-water. Since the introduction of iron as material for larger vessels it has, however, lost some of its former importance.

Yellow metal or *Muntz metal* (so-called after its inventor) consists generally of copper 60 to 62 parts, zinc 40 to 38.

The metal is prepared with the observance of certain precautionary measures in order to obtain it with as uniform a grain as possible, experience having shown that only fine-grained alloys of uniform density can resist sea-water. To obtain as uniform a grain as possible, small samples taken from the fused mass are quickly cooled and examined as to fracture. If the latter does not show the desired uniform grain, some zinc is added to the fused

mass. When this zinc has been intimately mixed with the mass a fresh sample is taken and tested, this being continued until the desired object is attained. It need scarcely be mentioned that considerable experience is required to tell the correct composition of the alloy from the fracture. The mass is finally poured into moulds and rolled cold.

Macht's yellow metal.—This alloy, consisting of copper 33 parts and zinc 25, has a dark golden-yellow color, great strength, and can be forged at a red heat, properties which make it especially suitable for fine castings.

Bobierre's metal, consisting of copper 66 parts and zinc 34, is claimed to be especially suitable for ship-sheathing.

From experiments made it has been learned that all alloys containing up to 58.33 per cent. of copper and up to 41.67 per cent. of zinc are malleable. There is, however, a second group of such alloys with 61.54 per cent. of copper and 38.46 per cent. of zinc, which are also malleable in the heat. The preparation of these alloys requires, however, considerable experience. It is best effected by melting the metals together in the ordinary manner, and heating the fused mass as strongly as possible; it must, however, be covered with a layer of charcoal-dust to prevent oxidation of the zinc. By the mass becoming thinly-fluid an intimate mixture of the constituent parts is effected. Small pieces of the same alloy previously prepared are then thrown into the liquid mass until it no longer shows a reflecting surface, when it is cast into ingots in iron moulds. The ingots while still red-hot are thrown into water, acquiring by this treatment the highest degree of ductility. The alloy properly prepared must show a fibrous fracture and have a reddish-yellow color.

Aich's metal.—This alloy named after its inventor, consists of a brass to which a considerable degree of tenacity has been imparted by an addition of iron. It is especially adapted for purposes where the use of a hard and, at the same time, strong metal is required.

According to analyses of various kinds of this metal, it shows, like other alloys, considerable variations in the quantity of the metals used in its preparation. Even the content of iron, to which the hardening effect is ascribed, may vary within wide limits without the strength, which is the principal property of this alloy, being modified to a considerable extent.

The best alloy, which can be called an Aich's metal, is composed of copper 60 parts, zinc 38.2, iron 1.8. The content of iron must be limited to from 0.4 to 3.0 per cent. Another Aich's metal showing excellent properties is composed of copper 60.2 parts, zinc 38.2, iron 1.6.

The hardness of Aich's metal is claimed to be not inferior to that of certain kinds of steel. It has a beautiful golden-yellow color, and is said to oxidize with difficulty, which makes it of great value for articles exposed to the action of air and water.

Sterro-metal.—The properties of this alloy approach closely those of Aich's metal. It consists of an alloy of copper, zinc, and iron, but contains a larger quantity of the latter. The composition of the alloy may vary considerably, a little tin being sometimes added. We give in the following an analysis of two varieties of sterro-metal of excellent quality:

Sterro-metal from Rosthorn's factory in Lower Austria.—Copper 55.33 parts, zinc 41.80, iron 4.66.

English sterro-metal (*Gedge's alloy for ship-sheathing*).—Copper 60 parts, zinc 38.125, iron 1.5.

The principal value of this alloy is its great strength, in which it is not surpassed by the best steel. While a wrought-iron pipe broke with a pressure of 267 atmospheres, a similar pipe of sterro-metal stood the enormous pressure of 763 atmospheres without cracking. Beside its strength it also possesses a high degree of elasticity, and on account of these properties is especially adapted for cylinders of hydraulic presses. As is well known, these

cylinders begin to sweat at a certain pressure, *i. e.*, the pressure in the interior is so great that the water permeates through the pores of the steel. With a cylinder of sterro-metal the pressure can be considerably increased without the exterior of the cylinder showing any moisture.

According to the purpose for which it is to be used, the sterro-metal can be made especially hard and dense, but this change in its properties is less effected by altering the chemical composition than by mechanical manipulation.

If cast sterro-metal be rolled or hammered in the heat, it acquires, besides strength, an exceedingly high degree of toughness. In hammering the metal special care must be had not to overheat it, as otherwise it easily becomes brittle, and cracks under the hammer.

A sterro-metal containing copper 55.04, zinc 42.36, tin 0.83, and iron 1.77 was tested by Baron de Rosthorn, of Vienna, and gave the following results:*

Material.	Tenacity.	
	Lbs. per square inch.	Kilogrammes per sq. centimetre.
Sterro-metal cast	60,480	4252
Sterro-metal forged	76,160	5354
Sterro-metal cold drawn	83,120	5984
Gun-bronze cast	40,320	2834

The specific gravity of this metal was 8.37 to 8.40 when forged or wire-drawn; it has great elasticity, stretching 0.0017 without set, and costs 30 to 40 per cent. less than gun-bronze. It has been forged into guns, cold from the casting.

Delta metal.—This alloy was introduced in 1883, by Mr. Alexander Dick, and on account of its strength and power of resisting the action of chemical influences is much used

* Holley. "Ordnance and Armor."

in the construction of machinery as a substitute for the more expensive bronze. The name "delta" was given to it by Mr. Dick, simply for the purpose of connecting it with his own name, delta being the Greek for the letter D, the initial of his surname.

Delta metal is a somewhat ferriferous brass with a fixed content of zinc—40 to 43 per cent. It is malleable at a red heat and distinguished by its strength. To prevent oxidation in remelting and to keep the composition invariable a small percentage of phosphor-copper or, still better, manganese-copper is added, That a content of iron is capable of increasing the strength of brass has been referred to in speaking of similar alloys, but in using such alloys containing iron many failures result because the iron alloys only with difficulty, and not always uniformly, with the other two metals. In making delta metal this drawback is overcome by first preparing an iron-zinc alloy with 8.5 per cent. iron, by dissolving the iron in melted zinc heated to a red heat, and combining this alloy with the rest of the metals. Besides iron, some manufacturers add small quantities of tin and lead; in some samples the presence of nickel has also been established. Examinations of articles of delta metal showed the following composition:

	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Copper	55.94	55.80	55.82	54.22	58.65
Zinc	41.61	40.07	41.41	42.25	38.95
Lead	0.72	1.82	0.76	1.10	0.67
Iron	0.87	1.28	0.86	0.99	1.62
Manganese	0.81	0.96	1.38	1.09	—
Nickel	trace	trace	0.06	0.16	0.11
Phosphorus	0.113	0.011	trace	0.02	—

No. I. is cast delta metal, No. II. wrought, No. III. rolled, and No. IV. hot stamped.

The advantages claimed for delta metal are great strength and toughness. It produces sound castings of close grain. It can be rolled and forged hot, and can stand a certain

amount of drawing and hammering when cold. It takes a high polish, and when exposed to the atmosphere tarnishes less than brass.

When cast in sand delta metal has a tensile strength of about 45,000 pounds per square inch, and about 10 per cent. elongation; when rolled, tensile strength of 60,000 to 75,000 pounds per square inch, elongation from 9 to 17 per cent. on bars 1.128 inch in diameter and 1 inch area.*

Wallace† gives the ultimate tensile strength as 33,600 to 51,520 pounds per square inch, with from 10 to 20 per cent. elongation.

Durana metal.—The alloy brought into commerce under this name resembles delta metal, but is somewhat richer in copper, and frequently contains tin, as well as antimony and aluminium. Five analyses gave the mean composition as follows:‡

Copper	Zinc	Iron	Aluminium	Tin Antimony
64.78	29.50	1.71	1.70	2.22

Like delta metal the alloy can be worked at a red heat, and is distinguished by its strength.

Tobin bronze.—As regards composition and properties this alloy closely resembles delta metal. Analyses of various samples showed the following results:

	I. Per cent.	II. Per cent.	III. Per cent.	IV. Per cent.
Copper	61.203	59.00	61.20	82.67
Zinc	27.440	38.40	37.14	3.23
Tin	0.906	2.16	0.90	12.40
Iron	0.180	0.11	0.18	0.10
Lead	0.359	0.31	0.35	2.14
Silver	—	—	—	0.07
Phosphorus	—	—	—	0.005

* *Iron* (London) Vol. 21, p. 159.

† Trans. of the Institution of Naval Architects, 1888, p. 374.

‡ Zeitschrift für angewandte Chemie. 1894.

The Ansonia Brass and Copper Company are, according to F. Lynwood Garrison,* the sole manufacturers of Tobin bronze. They claim to obtain 79,600 pounds per square inch tensile strength, an elastic limit of 54,257 pounds per square inch, and from 12 to 17 per cent. elongation with best rolled one-inch bars.

Tobin bronze, according to the inventor's claim, can be forged and stamped at a red heat as readily as steel. Bolts and nuts can be forged from it by hand or machinery, when cold drawn. Its increased density and high elastic limit, and the facility with which it can be upset, while hot, make it well adapted for special purposes. In forging Tobin bronze, it is stated that particular care must be taken to work it only at a cherry-red heat, and that it should not be worked at a black heat.

Alloy No. IV., given in the above table, is brought into commerce under the name of

Deoxidized bronze. It seems probable some deoxidizing flux containing phosphorus, similar to that used in the manufacture of phosphor-bronze, is made use of in the manufacture of this alloy. Deoxidized bronze is largely used for wood-pulp digesters, as it is found to resist the action of sodium hyposulphite and sulphurous acid remarkably well. Deoxidized bronze wire has a tensile strength in the neighborhood of 150,000 pounds per square inch.†

Of the mixtures of metals termed brass, the alloys given in the preceding are the most important used in the industries with the exception of aluminium brasses, which will be discussed under "Aluminium Alloys," ChapterXI. It will, of course, be understood that they by no means exhaust the number of alloys which can be included in the generic term, brass, that number being so large that they can scarcely be

* New Alloys and their Engineering Applications. Jour. of the Franklin Institute, June and September, 1891.

† F. Lynwood Garrison, New Alloys and their Engineering Application. Jour. of the Franklin, Inst., June and September, 1891.

enumerated. In examining a variety of brass, small variations in its quantitative composition can always be observed. No matter how small these variations may be, they nevertheless exert a great influence upon the physical properties of the respective alloys, so that an alloy differing but little in its chemical composition from another one, may nevertheless vary very much from it in regard to its physical qualities. Many manufacturers are of opinion that the physical properties of the alloys are also largely influenced by the mode of manufacture, and those whose products are especially distinguished by great uniformity always work according to a determined method. Hence the manufacture of brass is of equal importance with the composition of the alloys.

MANUFACTURE OF BRASS.

Before zinc was known in the metallic form, brass was prepared by fusing together with zinciferous ores, such as calamine or carbonate of zinc, as well as with cadmia, the zinc reduced by this process combining with the copper to an alloy. As is well known, the chemical composition of even the purest ores from the same locality always vary somewhat and it is almost impossible to obtain a mixture of metals of fixed properties and general uniformity. For the sake of completeness this antiquated process of manufacturing brass will here be briefly described. Manufacturers still working according to it, must, on the one hand, use very uniform zinc ore and, on the other, possess a thorough knowledge of the properties of brass so as to be able to tell from the color and fracture of a sample of the fused mass, whether the alloy possesses the requisite qualities or whether it requires the addition of a further quantity of zinc ore or of copper. The production of brass with the use of zinc ores is less expensive, but more tedious and troublesome than by the direct fusion of pure metals.

a. Manufacture of brass according to the old method with the use of zinc ores.—Previous to melting, the ores

have to be subjected to a preparatory treatment to remove, as far as possible, admixtures of foreign metals such as lead, arsenic, antimony, which would impair the quality of the brass. The native calamine is calcined to expel carbonic acid, sulphur and other volatile matter, and forms zinc oxide. The calcined ore is then ground in a mill, the galena contained in it removed by washing, and the dried ore mixed with about one-fourth its volume of charcoal. The mixture is brought into large crucibles with alternate layers of granulated copper. Powdered charcoal is then thrown over the whole and the crucibles are covered and luted. The old form of furnace consisted of a cone with base downward and the apex cut off horizontally. The crucibles were placed upon a circular grate or perforated iron-plate upon the hearth. A sufficient quantity of fuel was heaped around the crucibles, and a perforated cover of bricks or clay was fitted to the mouth which served as a register to regulate the heat. After the alloy is supposed to be formed (the time varying from 10 to 20 hours, according to the nature of the calamine and the size of the crucibles), the heat is increased, so as to fuse the whole down into one mass. The till is then thrown up, and a workman, standing over the opening, grasps the crucible between the jaws of a pair of tongs and lifts it out of the furnace. The refuse is skimmed off, and another workman then seizes the crucible with a pair of tongs and pours the contents into iron moulds, guiding the stream with an iron rod. During this process there is a considerable combustion of zinc, the metal burning with its characteristic blue flame. When the material is good a single fusion is sufficient, but the finer sorts undergo a second fusion with fresh calamine and charcoal.

The crude brass may show several defects in regard to its composition. It may either contain too much zinc or copper, or the reduction of the zinc may not have proceeded in a complete manner. In such cases it is possible to im-

prove the alloy by a corresponding addition of copper, zinc ore, or charcoal, and by again fusing it. Sometimes pieces of brass or metallic zinc are also added.

b. Manufacture of brass by the direct fusion of the metals.—At the first glance this would appear to be a very simple operation; it is, however connected with many difficulties, and considerable skill is required to produce brass answering determined demands in regard to fusibility, tenacity, etc. In most factories the fusion of the metals is still effected in crucibles heated in reverberatory furnaces. For many years experiments have been made to do away with the crucibles and effect the fusion of the metals directly in special furnaces. It is evident that such a process of production would be considerably cheaper, as there would be no expense for crucibles and the consumption of fuel be considerably less. The use of a furnace in which the metals could be melted down in large quantities would have the further advantage of obtaining at one operation a large quantity of brass of the same quality.

The results of experiments made in this direction have, however, been so unsatisfactory as to force a return to the older and more expensive method of fusion in crucibles. The general introduction of furnaces for melting down the brass cannot, however, be considered as entirely abandoned, as the technical difficulties in the way will, no doubt, be overcome, before long. More recently experiments on a large scale have again been instituted by well-known manufacturers, which hold out a hope of final success. For the present we must, however, confine ourselves to a description of the best constructions of furnaces for crucibles.

The manner of constructing these furnaces depends chiefly on the fuel to be used (coal, coke) and on the number of crucibles to be placed in the furnace at one time. Generally speaking, the furnaces for a certain kind of fuel agree in most respects, the variations being chiefly in the arrangement of the crucibles in the furnace, and the manner of distributing the flame around them.

We first give a description of a furnace especially adapted for the use of coke.

The furnace, Figs. 10 and 11, consists of a vault of refractory material and is about 3¼ feet high. On the narrowest place of the vault is an aperture through which the furnace communicates with a well-drawing chimney. The

Figs. 10 and 11.

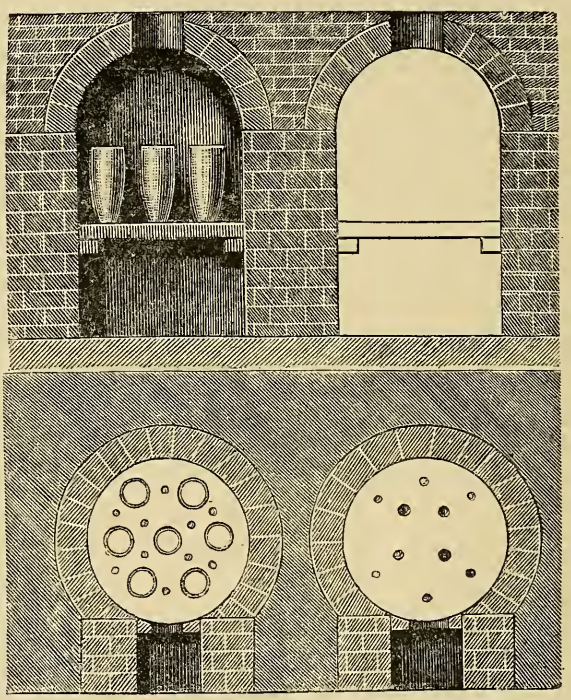
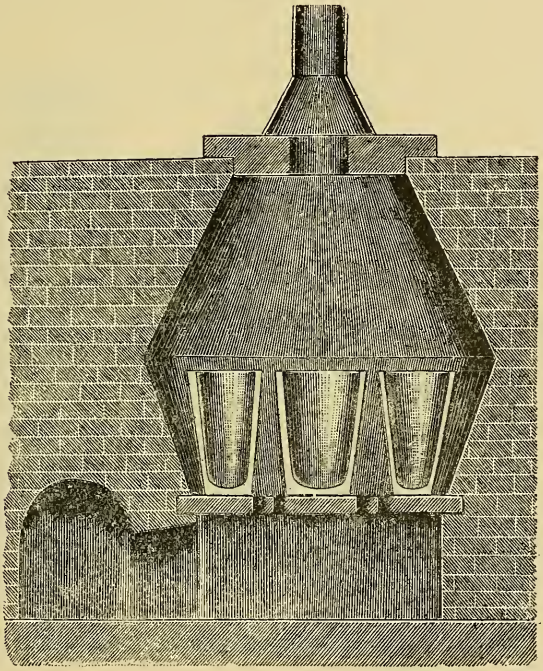


plate upon which the crucibles for melting the brass stand has seven apertures so arranged that six of them are in the periphery of a circle, while the seventh forms the center of the circle. Between these larger apertures serving for the reception of the crucibles are smaller ones, which admit the air from below into the furnace. The bottom plate consists of a thick cast-iron plate coated with a layer of

fire-clay. The six crucibles standing on the periphery of the circle have a height of 1.18 feet, with an upper diameter of 0.65 foot, which corresponds to a bottom diameter of 0.55 foot.

The crucible sitting in the center hole is called the king crucible, and being more exposed to the heat is generally somewhat larger; it is, as a rule, 1.18 feet high with an

FIG. 12.



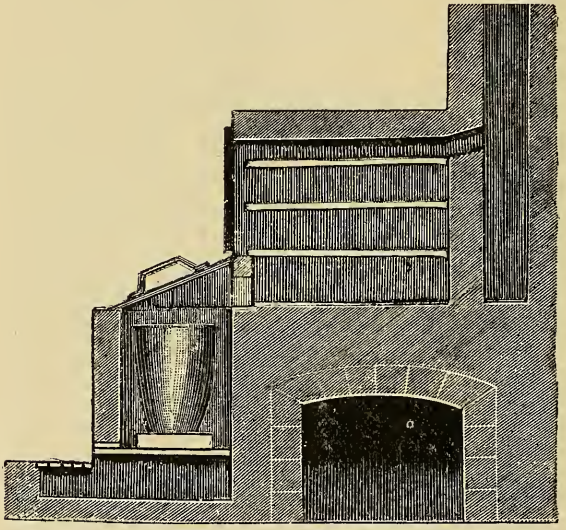
upper diameter of 0.75 foot. The smaller crucibles hold about 92 to 97 pounds of metal each, and the king crucible about 132 pounds.

Fig. 12 shows another construction of a brass furnace. As will be seen from the illustration, the space in which the crucibles are placed has the form of two truncated cones touching each other with the basis, a shaft being

thus formed in which less fuel is consumed than in a furnace having the form of a cylinder. In place of coke, charcoal may be used in this furnace if the local conditions are such as to allow of its employment without increasing the cost of the brass.

In the preparation of plate-brass the fused metal has to be cast in special moulds to solidify. It is, however, of importance that this solidification should not take place too rapidly, as otherwise the properties of the brass might be

Fig. 13.



injured. To prevent too rapid cooling the moulds serving for the reception of the fused mass are strongly heated, special furnaces having been constructed for the purpose in which the gases escaping from the actual melting space are utilized for heating the moulds. Fig. 13 shows the construction of such a furnace in cross-section.

The crucibles in which the charge is to be melted stand upon a grate; the fuel is introduced from above, and the gases of combustion pass through a flue into a space

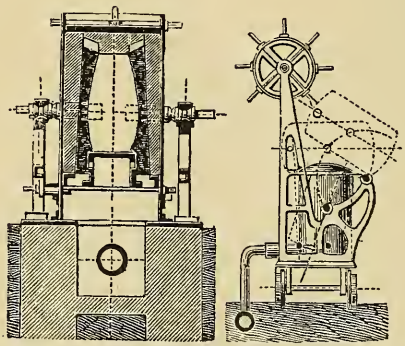
divided into several low stories in which the moulds are placed. With the use of coke or charcoal the work is very convenient, since no smoke is developed which could possibly contain combustible combinations. As will be seen from the above descriptions of furnaces for the use of coke or charcoal, no special provisions are required to insure a complete combustion of the fuel, it being sufficient to connect the furnace with a chimney producing a moderately strong draught, With the use of coal care must, however, be had to arrange the furnace in such a manner as to insure the complete combustion of all gaseous products evolved from the coal, as otherwise there would be a considerable loss of heat.

The arrangement of furnaces for the use of coal is modified in various ways. In one form of construction the coal is burned upon an ordinary grate, the gases of combustion passing through apertures in a vault of refractory material into a space in which the crucibles are placed. In other constructions, the fire-box is entirely separated from the melting-space, being only connected with it by flues led off at the sides through which the flame passes around the crucibles. Other constructions might be advantageously used for melting down brass. By, for instance, arranging the furnace so as to heat the crucibles by gas, the flame could be suitably regulated by a slide, and with the use of a generating furnace a number of melting furnaces could be kept going at one time. The generating furnace would, of course, have to be placed so as to form the center of a circle on the periphery of which the separate melting furnaces are located and connected with the generating furnace by suitable flues. With, suppose, six such melting furnaces, three could be supplied with heat, while the others, after the removal of the crucibles, would be charged with fresh material.

Fig. 14 shows Piat's revolving crucible furnace. The crucible remains stationary in the furnace, at least for

several meltings. Fusion itself is effected by burning coke heaped around the crucible, combustion being accelerated by a blower. The blast-flue enters below the grate upon which is placed the crucible-stand, and the products of combustion pass through a pipe in the upper portion of the furnace into a chimney, or with larger furnaces into a hot blast-stove. The illustration shows the furnace in a vertical (working) position. From this position it can, after shutting off the blast, be brought by revolving around a horizontal axis into the position required for pouring out the metal, a spout with which the crucible is provided fit-

Fig. 14.



ting accurately to the pouring gutter of the furnace. In case the mould cannot be brought to the furnace, the latter is so constructed as to allow of being raised and being brought to the mould by means of a crane; the furnace together with its support may also be placed upon a carriage. With the use of such a furnace lifting the crucibles with tongs is entirely done away with.

In conclusion a few words may be said in regard to the construction of furnaces in which the fusion of the brass is effected directly upon the hearth. Generally speaking, they must be so arranged that the copper can be quickly melted down upon a flat hearth, care being had that the gases pass-

ing over the copper contain a small excess of unburnt bodies, as the presence of free oxygen in the gases might produce an oxidation of the copper, and the resulting admixture of cuprous oxide injure the quality of the brass. After being fused the copper is to be strongly heated, and the zinc, together with any brass waste, both previously heated, introduced as quickly as possible. It is advisable to connect the furnace with two preparatory heating spaces, showing different temperatures. In the space showing the lowest temperature the zinc is heated as nearly as possible to its melting point, and in the hotter space the brass waste which is to be added to the fused mass.

By introducing, as rapidly as possible, the materials thus heated into the heated copper, a too rapid cooling off of the latter by yielding heat to the zinc need not be feared. By this precautionary measure of preparatory heating the metal will remain thinly fluid, even after the introduction of the zinc and the waste brass, and the resulting alloy will be perfectly uniform as regards fracture, hardness, and color.

The manner in which fusion is effected varies somewhat in the different works. In furnaces in which the king-crucible stands in the center of a circle and the rest on the periphery, the work is generally carried on as follows:

One of the crucibles is lifted from the furnace, and being placed alongside of it is first charged with a small quantity of brass-waste mixed with a certain quantity of pulverized charcoal. Upon this base the mixture of copper and zinc in suitable proportions, previously weighed off for each crucible, is placed and the whole covered with a layer of a mixture of brass-waste and pulverized charcoal. It is also advisable to cover the surface of the contents of the crucible with as high a layer of pulverized charcoal as possible, this preventing at least to some extent a too strong volatilization of the zinc. In brass foundries the waste resulting from casting and otherwise is always melted down with a new charge of the crucibles. The centre crucible, the so-

called king-crucible, is generally charged last. In some foundries it is even customary to leave it entirely uncharged, it forming then, so to say, the inner casing of the furnace. This practice, however, cannot be recommended.

The period of the complete fusion of the charge depends on the size of the crucibles, the fuel used, and on the construction of the furnace itself, but should not be longer than from two to five hours. After placing the crucibles in the furnace the fuel (if coke or charcoal be used) is heaped around them, or the coal placed upon the grate and ignited. In working with furnaces provided with a movable plate the latter is from time to time lifted off, in order to see that the surface of the melted metal remains covered with charcoal. When by dipping a rod into the crucibles it is observed that the contents are thoroughly liquefied, the casting can be either at once proceeded with, or samples may first be taken to test the quality of the brass, and, if necessary, change its properties by additions to the fused mass.

While in the course of fusion care must be had to keep the apertures through which the air is admitted to the fuel free, towards the end of the operation they are covered as much as possible in order to save fuel. It is also of importance not to force the heating of the finished alloy further than is absolutely necessary, since by strong overheating a considerable portion of the zinc volatilizes, and the alloy may acquire properties entirely different from those desired.

Casting Brass.

THE casting of brass requires certain precautionary measures in order to obtain homogeneous pieces as free from flaws as possible. As regards the mode of casting we especially distinguish two different methods, viz: Ingot-casting and plate-casting, the former serving for casting brick-shaped pieces, which are to be remelted for further

working or at once brought into the required shape, and the latter for casting plates to be rolled out into sheets.

a. Casting of ingots.—If the brass is to be cast in the shape of bricks, or cubes, or is directly to be used for casting various articles, the operation is carried on as follows: The king-crucible is generally left empty, and after the brass in the other crucibles is thoroughly melted down, is lifted from the furnace and placed in a depression in front of it filled with glowing coals. One crucible after the other is then taken from the furnace and its contents emptied into the king-crucible. As soon as it is filled the surface of the fused metal contained in it is covered with charcoal and the whole allowed to stand quietly about 15 minutes in order to bring about a uniform mixing of the masses emptied from the different crucibles. After this period, the charcoal is removed from the surface, and, after vigorously stirring the contents of the crucible several times with an iron rod, the fused metal is poured into the moulds.

As will be seen from the preceding description, the king-crucible answers here the purpose of a sump, and may be suitably replaced by one. For this purpose another furnace, in which the sump stands free and can be heated to a bright red heat, has to be erected in front of the furnace containing the crucibles. This sump then serves for the reception of the fused brass, and by charging the king-crucible also with metal, the space occupied by it in the center of the furnace can be advantageously utilized. By arranging several melting furnaces around the sump-furnace and with a proper division of the work, only one sump is required, it being charged in rotation with the contents of the crucibles from the separate furnaces.

The moulds for casting ingots of brass are similar to those used for casting pig-iron. The patterns for the moulds are of wood, and have generally the form of bricks with oblique sides. The patterns are pressed alongside each other in wet moulding sand, a small gutter being left be-

tween each two moulds through which the metal after one mould is filled runs into the other.

The object being not so much to give the ingots a beautiful appearance as to obtain them in a handy form, the sand for making the moulds need not be especially fine. The cold ingots of brass have quite a rough surface, and must be freed from adhering grains of sand by rubbing.

For casting articles to be subsequently turned or worked with the file, special care is required in making the mould. As a rule the ingots are remelted in a wind furnace, and the quality of the article to be cast is regulated by the addition of pieces of brass or zinc to the fused metal. For remelting brass graphite crucibles are generally used, less dross adhering to their walls than to those of the rougher clay crucibles.

The moulds used for casting articles of brass are sometimes made of loam, and must be sharply dried before use to prevent cracking. Suitable moulding sand is, however, generally preferred. The condition of the sand is of great importance for the surface of the cast article; if it be too meager the surface is rough, and requires much after-work in turning or filing. Meager sand is improved by adding a small quantity of ordinary flour paste or some sugar syrup. If the sand is too fat, this property is decreased by the addition of some finely pulverized charcoal.

In order to obtain perfect castings great attention must be paid to the temperature of the fused brass. Overheated metal gives, as a rule, porous castings, and if it be too cool the mould is incompletely filled out, which with delicate articles may spoil the entire casting. The metal must be poured in an uninterrupted stream into the mould, otherwise flaws will, as a rule, be formed and the casting be useless. In conclusion it may be remarked that in making the moulds, vents must be provided for the escape of the aqueous vapor evolved.

b. Casting of plate-brass.—For the preparation of sheet-

brass or wire-brass the metal has to be cast in the form of plates of corresponding thickness. It being absolutely necessary for the metal to retain the property of ductility, special precautions must be taken in executing the casting.

Many attempts have been made to use iron moulds, but in most cases the castings turned out failures, on account of the brass cooling off too rapidly. This evil might, however, be overcome by heating the moulds in a special furnace previously to casting and returning them to the furnace after casting, where by a suitable regulation of the temperature, the castings could be cooled off as slowly as desired. Such furnace could be built on the same principle as the cooling furnace used in glass houses.

Loam moulds give good castings, but have the disadvantage of breaking readily, which, to be sure, might be overcome by edging the loam plates with band-iron. At present small moulds of sand are frequently used in many foundries, which must, of course, be thoroughly dried in special furnaces previously to casting. With the use of small moulds and careful work, faultless plates can be readily cast, while with large moulds it frequently happens that some places of the plate are defective and have to be cut out.

In many places granite moulds are still in use, and yield, according to the statements of many manufacturers, the best results. The preparation of these moulds requires great care, the following points deserving special attention: The granite plates have to be provided with a uniform coating of clay, which must always be kept in such a condition as to insure the utmost uniformity in the surface of the plates. To prevent the cracking of the coating of clay, it is covered, after thorough smoothing, with a thin layer of cow-dung.

The granite plates thus prepared are arranged in the following manner: The upper plate is suspended over the lower one, the space or mould between the two being

limited by iron bars laid on the lower stone, which is a little longer than the upper one, and projects to the front so as to form a lip or mouth piece for receiving the metal. The plates are bound together with iron, and raised on one side so that they stand at an angle of 45°. As soon as the casting is finished and the metal is supposed to be solidified, the sheet of brass is carefully taken from the mould. With sufficient precautions such granite moulds can be used for a long time without the coating of clay becoming damaged, and the sheets turn out very uniform after the mould has once been heated by several castings. One and the same mould is frequently used continually, in order to keep it warm, and if it has to stand empty for some time it is enveloped in a bad conductor, as a coarse carpet, to prevent its cooling. If the mould is damaged it must be carefully mended, and the mended places sharply dried to prevent cracking.

The sheets of brass taken from the mould are subjected to a mechanical cleansing, and at the same time carefully inspected, defective sheets being remelted.

At the present time the plate-brass obtained by casting is generally worked into sheet-brass, which was formerly prepared by hammering, but now by rolling. In some cases rolling is succeeded by hammering, as, for instance, in the case of the very thin sheet-brass known as Dutch metal, which is distinguished by the peculiar clear sound it emits on being pressed together. Thicker plates are occasionally prepared for rolling by hammering. After each passage through the rolls the sheets are heated in a heating furnace, quenched to obtain greater ductility, and then rolled cold until reduced to the desired thickness. In working brass which is only ductile in the heat, the sheets must of course pass in a hot state through the rolls until reduced to the proper size. Before rolling, the sheets, and sometimes the rolls also, are coated with oil. After passing through the rolls the sheet-brass is finally subjected to a

treatment which decides whether it is to be soft and flexible, or hard and elastic. For soft sheet the rolled sheet-brass is again heated and quenched, while for hard and elastic sheet the heating is omitted, and the sheet several times more rolled cold.

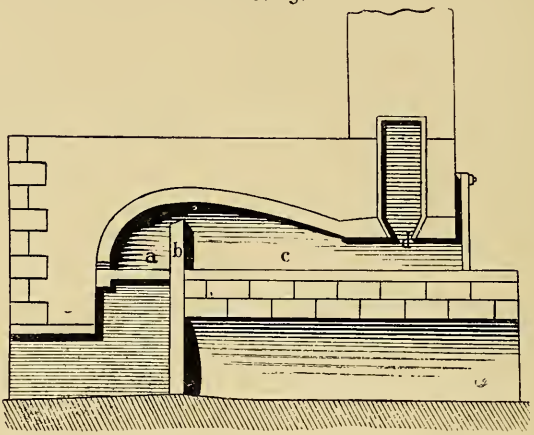
The sheets are generally heated in a reverberatory furnace heated by wood or gas. Siemens has constructed regenerative gas reverberatory furnaces for heating. Coal, if used in such furnaces, yields, on account of the sulphur contained in the gases of the fire, a product which after cleansing does not show a beautiful yellow, but a red, color, which is due to the copper having entered into combination with the sulphur contained in the gases of the fire. If coal is to be used as fuel, either furnaces with iron or clay muffles washed by the flame are used, or the coal is converted into gases, which before combustion are sucked by means of an exhauster through milk of lime to remove their content of sulphurous acid. Regenerative gas firing is advisable, especially for large heating furnaces, since by directing the flame now to one side and then to the other, a more uniform heat can be obtained and the temperature more readily regulated.

Figs. 15 and 16 show a reverberatory furnace for wood firing. It is furnished with a grate, *a*, 4 feet long and 2 feet wide; the fire-bridge *b* projects about 1¾ feet above the hearth *c*, which is on a level with the grate; the hearth is about 9 feet long and 4 feet wide. The arch behind the fire bridge is about 3 feet high, and the flue *d* opens about 1 foot above the hearth. The sheets rest upon the rails *e* so that they are also played upon from below by the flame.

The sheets to be heated are frequently placed upon a carriage running upon wheels and rails, which when the charge is heated is withdrawn and replaced by another loaded carriage. This plan has the disadvantage that through the intermediate space required for the movement of the carriage and the expansion of the bottom, much cold

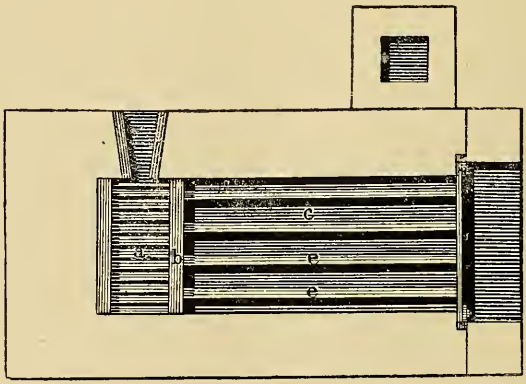
air passes between the bottom of the hearth and the furnace into the heating space and cools off the furnace,

Fig. 15.



whereby more time, and consequently more fuel, is required for heating. In some brass factories this evil has been overcome as follows: On both sides the entire length of the furnace, run, below the bottom of the hearth, hearth-

Fig. 16.



plates with their angles turned downward. Corresponding to this, angle-irons turned upward are placed with sufficient

play on both sides of the carriage so that on the carriage wheels a sort of gutter is formed which is filled with fine sand. On pushing the carriage into the furnace the angle-irons of the furnace sink into the sand and thus prevent the access of air. This arrangement is said to decrease the consumption of fuel one-third.

Cleansing or Pickling of Brass.

The finished sheets have a black color, which is partially due to the formation of cupric oxide on the surface and partially to sulphur combinations formed, as previously mentioned, by heating with coal in annealing. As a rule brass is brought into commerce in a bright state, the only exception being the thicker sheets, which retain their black coating. In order to impart to the sheet its characteristic beautiful yellow color, it is subjected to a final operation termed *pickling* or *dipping*. This operation simply consists in treating the sheet with acid, which removes the layer of oxide to which the black color is due. The pickling is commenced by placing the sheets in a fluid consisting of 10 parts of water and 1 of sulphuric acid. The layer of oxide quickly dissolves in the fluid and the sheets show the pure yellow brass color. After this operation the sheets may be at once washed and dried, and brought into commerce.

In most cases the sheets are, however, subjected to a second treatment with acids in order to impart to them a beautiful color; hence the treatment with sulphuric acid is generally termed preparatory pickling. As the actual pickle, either nitric acid by itself is used, or a mixture of two parts of nitric acid and one part of sulphuric acid. Pickles containing nitric acid possess the property of dissolving zinc from the brass quicker than copper, the surface of the sheet acquiring in consequence of it a warmer tone, shading more or less into reddish. By exercising great care dilute nitric acid by itself may be used as a

pickle, but the sheets must be immediately washed, since if only the slightest trace of the acid remains, they acquire after some time a greenish color due to the formation of a basic cupric nitrate.

It has been observed that nitric acid containing a certain quantity of nitrous acid yields especially beautiful shades of color. To obtain them a small quantity of organic substance is added to the nitric acid or to the mixture of nitric and sulphuric acids. The most curious substances are used for the purpose, snuff, for instance, being highly recommended as especially efficacious in producing beautiful colors. The use of such substances is, however, entirely superfluous, there being a number of cheaper organic substances which, when brought together with concentrated nitric acid, evolve nitrous acid. The cheapest of these materials is dry saw-dust, the nitric acid acquiring a short time after its introduction an orange-yellow color, which is due to the products of decomposition of the nitric acid, prominent among which is nitrous acid. After taking the sheets from the pickle they are washed, best in running water, in order to remove the last traces of acid.

By quick pickling the articles are obtained bright by the removal of the layer of oxide from the smooth surface of the metal. But sometimes a dull lusterless surface is to be imparted to the brass, which is effected by treating the articles with a boiling pickling-fluid composed also of nitric and sulphuric acids. In many factories this pickle is prepared by dissolving 1 part of zinc in 3 of nitric acid and mixing the solution with 8 parts each of nitric and sulphuric acids. The solution is heated in a porcelain dish, and the articles to be pickled dipped in it 30 to 40 seconds. In dipping the brass articles large masses of red-brown vapors originating from the products of decomposition of the nitric acid are evolved which strongly attack the lungs. The operation should therefore be executed under a well-drawing chimney, or, still better, in an open space.

The pickled articles have a gray-yellow color, and in order to bring out the pure yellow color are immersed for a few seconds in pure nitric acid. They are then drawn through a weak solution of soda or potash, and finally washed. As the bright metal loses its beautiful color on exposure to the air in consequence of oxidation, the articles after drying must be coated with good varnish.

TOMBAC.

The term tombac is applied to copper-zinc alloys which on account of their small content of zinc—at the utmost 18 per cent.—have a golden-yellow, reddish to red-brown color instead of the yellow brass color. Articles of such an alloy having the appearance of gold are said to have been brought, in the 17th century, to Europe from Siam, and the Malayan name *tambaga* (actually copper) was converted into tombac. According to other statements the word has been formed by reversing the syllables of the Chinese packfong or packtong (white copper),

If such alloys consisting essentially of copper and zinc, have been used for castings, especially machine parts, they are sometimes called red brass to distinguish them from the more zinciferous yellow brass.

Pure tombac, *i. e.*, the alloy free from tin, lead and other bodies impairing flexibility, is distinguished by a comparatively high degree of ductility at the ordinary temperature but, like most all other varieties of brass, cannot be worked at higher temperatures. It is chiefly used for the manufacture of fictitious gold articles which possess a gold-like color, and are generally made by "striking up" in a die under a press or a drop-hammer, for which purpose a very flexible and tenacious metal is required, as otherwise the articles would crack. To this class belong cheap jewelry and ornaments, buttons and Dutch gold leaf. The varieties of tombac which contain not less than 10, and not over 18 per cent. zinc possess a color most closely resembling that

of gold. Articles made from such alloys are generally thinly gilded as otherwise they soon turn black and require frequent cleaning.

While tombac generally contains 84 to 85 parts of copper and 15 to 16 parts of zinc; the proportions vary considerably as may be seen from the following table.

	Parts.		
	Copper.	Zinc.	Lead.
Cast-tombac, German	87.00	13.00	—
" English	86.38	13.62	—
Tombac, German (Oker)	85.00	15.00	—
" " (Hegermühl)	85.30	14.70	—
" Paris (red)	92.00	8.00	—
" for gilding, German	97.80	2.20	—
" " French	86.00	14.00	—
" German (Lüdenscheid)	82.30	17.70	—
" French (yellow)	80.00	17.00	3.00
" golden-yellow	89.97	9.98	0.05
" " "	82.00	17.50	0.50

The best Berlin alloys (so-called bronzes) for lamps and chandeliers contain, as a rule, 80 per cent. copper and 20 per cent. zinc. For ordinary work an alloy with 33 per cent. zinc is used. Castings to be worked with a lathe contain 40 per cent. zinc. The so-called *Lyons gold* is tombac.

The color of tombac varies from pure copper-red to orange-yellow, according to the content of copper, though a red color is by no means a criterion as regards the content of copper, since an alloy of 49.3 parts of copper and 50.7 of zinc is redder than one of 4 parts of copper and 1 of zinc. The more copper the alloy contains the more fine-grained and ductile it generally is.

Many small articles, as. candle-sticks, inkstands, etc., which are sometimes gilt, are made from a compound designated in commerce as bronze, which is, however, not bronze, but only resembles it in color. Such alloys are also frequently used for casting small statues, for which they are

well adapted, since they fill the moulds very uniformly. The composition of these alloys varies very much, though zinc and copper are, as a rule, the actual constituents, an admixture of tin occurring only occasionally. We give a few compositions of this (imitation) bronze:

	Parts.		
	I.	II.	III.
Copper	80	67	76
Zinc	20	33	24

Mannheim gold or similor.—This alloy has a beautiful golden-yellow color. Its composition varies considerably:

	Parts.	
	I.	II.
Copper	83.7	89.8
Zinc	9.3	9.6
Tin	7.0	0.6

The alloy may also be obtained by melting together 69.6 parts of copper, 29.8 of brass, and 0.6 of finest tin.

Mannheim gold was formerly much used in the manufacture of buttons and pressed articles of a gold-like appearance, but it has recently been superseded by alloys which surpass it as regards beautiful color.

Chrysochalk (*gold-copper*).—This term is applied to several alloys resembling gold, which may consist of copper 90.5 parts, zinc 7.9, lead 1.6, or of copper 58.68, zinc 39.42, lead 1.90.

The beautiful color of this alloy soon disappears on exposure to the air, but can be preserved for some time by coating articles manufactured from it with a colorless lacquer. Chrysochalk is generally used for ordinary gold imitations, as watch-chains, articles of jewelry, etc.

Chrysorin.—This alloy, prepared by Rauscherber, consists of 100 parts of copper and 51 of zinc. Its color resembles that of 18 to 20 carat gold, and does not tarnish in the air.

Pinchbeck.—The alloy known under this name was first manufactured in England, and is distinguished by its dark gold color which comes nearest to that of gold alloyed with copper. Pinchbeck being very ductile can be rolled out into very thin plates, which can be brought into any desired shape by stamping. The alloy does not readily oxidize in the air, and is, therefore, well adapted for cheap articles of jewelry, for which it is principally used. Pinchbeck answering all demands is composed of—

	Parts.	
	I.	II.
Copper	88.8	93.6
Zinc	11.2	6.4

Or,

Brass	1.0	0.7
Copper	2.0	1.28
Zinc	—	0.7

French orëide.—This alloy is distinguished by its beautiful color which closely resembles that of gold. In addition to its beautiful color it is very ductile and tenacious so that it can readily be stamped and rolled; it also takes a very fine polish. The directions for preparing this alloy vary very much, some from Paris factories showing the following compositions:

Copper	90.0	85.5	82.75	Parts.
Zinc	10.0	14.5	16.40	
Tin	—	—	0.55	
Iron	—	—	0.30	

According to a special formula, orëide is prepared as follows: Melt 100 parts of copper and add, with constant stirring, 6 parts of magnesia, 3.6 of sal ammoniac, 1.8 of lime, and 9 of crude tartar. Stir again thoroughly, and then add 17 parts of granulated zinc, and after mixing it

with the copper by vigorous stirring, keep the alloy liquid for one hour. Then remove the cover of froth and pour out the alloy.

Talmi or talmi-gold.—Cheap articles of jewelry, chains, earrings, bracelets, etc., were first brought into commerce from Paris under the name of talmi-gold, which were distinguished by beautiful workmanship, low price, and great durability. Later on, when this alloy had required considerable reputation, other alloys, or rather metals, were brought into commerce under the same name, which retained their beautiful gold color, however, only as long as the articles manufactured from them were not used.

The finer quality of talmi-gold retains its pure gold color for some time, and consists actually of brass or copper or tombac covered with a thin plate of gold combined with the base by rolling. The plates thus formed are then rolled out by passing through rolls, whereby the coating of gold not only acquires considerable density, but adheres so firmly to the base that articles manufactured from the metal can be used for years without losing their beautiful appearance.

In modern times articles of talmi-gold are brought into market which are simply electroplated, the coating of gold being in many cases so thin that by strong rubbing with a rough cloth the color of the base shows through. Such articles, of course, lose their gold-like appearance in a short time.

In the following table we give the composition of a few alloys used in the manufacture of articles of talmi-gold; it will be seen that the content of gold varies very much, the durability of the articles manufactured from the respective alloys being, of course, a corresponding one. The alloys I., II., and III. are genuine Paris talmi-gold; IV., V., and VI. are imitations which are electroplated, and VII. is an alloy of a faulty composition to which the gold does not adhere.

	I.	II.	III.	IV.	V.	VI.	VII.
Copper	89.88	90.79	90.00	90.69 88.16	87.48 83.13	93.46 84.55	86.4
Zinc	9.32	8.33	8.9	8.97 11.42	12.44 16.97	6.60 15.79	12.2
Tin	—	—	—	—	—	—	1.1
Iron	—	—	—	—	—	—	0.3
Gold	1.03	0.97	0.91	0.05 —	0.03 —	0.05 —	—

Tissier's metal.—This alloy is distinguished by great hardness and differs from the previously described compounds in containing arsenic. It has a beautiful tombac red color. Its composition is not always the same, the quantities of the component metals varying within wide limits. The alloy actually deserving the name is composed of copper 97 parts, zinc 2, arsenic 1 to 2.

According to this composition Tissier's metal may be considered a brass containing a very high percentage of copper and hardened by an addition of arsenic. It is sometimes used for axle-bearings, but can be very suitably replaced by other alloys, to be mentioned further on, which are preferable to it on account of lacking the dangerous arsenic.

Tournay's metal.—This alloy is much used by the Paris manufacturers of bronze articles, and on account of its great ductility can be advantageously employed for the manufacture of cheap jewelry to be made from very thin sheet. It is also well adapted for the manufacture of buttons. It is composed of copper 82.54 parts, zinc 17.46.

Platina, a white alloy, especially suitable for buttons, contains 80 parts brass and 20 copper.

Manilla gold consists of copper and zinc, or lead.

Dutch leaf or Dutch gold. Copper 77.75 to 84.5 per cent., zinc 15.5 to 22.25 per cent.

The alloy is pale to dark yellow according to the propor-

tions of copper and zinc used. Being very ductile it is employed in the manufacture of Dutch leaf or Dutch gold.

The alloy is melted in graphite crucibles and cast in iron moulds to semi-circular bars about 24 inches long and ½ or or ¾ inch wide. The bars are then rolled cold and each resulting ribbon is made into a pile about 2 feet long and beaten under the hammer to a ribbon about 1½ inches wide. It is then annealed and beaten into a ribbon 2¼ inches wide, and, after further annealing, into one 3½ to 4 inches wide. This last ribbon is pickled in dilute sulphuric acid, washed, boiled bright in argol solution, washed, brushed and quickly dried. The ribbons are then cut up and 1000 to 2000 pieces made into a pile and beaten under the hammer. The material is then again cut up, the leaves are placed between parchment and reduced by beating to about 5¾ inches square. Each leaf is then cut up into 4 pieces, which are placed between gold beaters' skin and beaten by hand to about four times the size of the original leaf. The hammer used weighs 5½ to 11 pounds, and the work is performed upon an anvil of dolomite by alternately beating with the right and left hand, and turning the package with the free hand. The package is made up of from 800 to 1000 gold beaters' skins, between which the metal leaves are placed; on top and bottom come six parchment leaves, and the whole is then tied up in parchment. After the above-mentioned hammer has been used for about one hour, beating is continued for about 2 hours with a hammer weighing from 12 to 16½ lbs. To prevent the leaves from adhering to the skins in consequence of the development of heat, they are coated with gypsum. The leaves when taken from the skins are trimmed and placed in small books between tissue paper rubbed with rouge. Each book contains 21 to 25 leaves.

Dutch leaf is used for gilding all sorts of articles, and its beautiful color may be preserved for some time by applying a coat of thin colorless or slightly yellow lacquer. By add-

ing to the latter a small quantity of a pure color—aniline colors being well adapted for the purpose—the color of the leaf can be readily changed to red, green, violet, etc.

Bronze powders.—The bronze powders used for coating metallic and non-metallic articles (wood, plaster of paris, oil-cloth, wall paper, etc.), consist of tombac-like alloys. For colors shading strongly into white, metallic mixtures with a high percentage of zinc are used, and for those approaching more closely to a pure red, alloys with a large content of copper.

The many shades of color found in commerce are, however, not produced by the employment of different compounds, but by heating the alloys converted into an impalpable powder until the desired shade is obtained by the formation of a thin layer of oxide upon the surface of each particle. In modern times bronze powders are brought into commerce showing beautiful green, blue, and violet colors, which are, however, not obtained by the formation of a layer of oxide, but by coloring the metallic powder with aniline color. The manner of preparing bronze powders has been recently much improved by the use of suitable machines for the conversion of the alloys into powder.

In metal-leaf factories the waste resulting in rolling out and hammering is used for the preparation of bronze powder. According to the old method the waste was rubbed with a honey—or gum—solution upon a stone until a mass consisting of fine powder combined to a dough by the honey—or gum—solution was formed. This dough was thrown into water, and after the solution of the agglutinant the metallic powder was dried, and subjected to oxidation by mixing it with a little fat and heating it in a pan over an open fire until the desired shade of color was obtained. At the present time this laborious and time-consuming method has been much shortened by the use of suitable machines, and of alloys prepared by melting together the metals in suitable proportions for powders which do not

require to be colored by oxidation. These alloys are beaten out into thin leaves by hammers driven by steam. The leaves are then converted into powder by forcing them through the meshes of a fine iron-wire sieve with the assistance of a scratch-brush. This rubbing through is effected with a simultaneous admission of oil, and the mass running off from the sieve is brought into a grinding machine of peculiar construction—a steel-plate covered with fine blunt-pointed needles revolving over another steel-plate. In this machine the mass is reduced to a very fine powder, mixed, however, with oil. The powder is first brought into water where the greater portion of the oil separates on the surface. The metallic mass lying on the bottom of the vessel is then subjected to a strong pressure, which removes nearly all the oil, the small quantity remaining exerting no injurious influence, but being rather beneficial, as it causes the powder to adhere with greater tenacity to the articles to which it is applied.

In the following table we give the compositions of the alloys for some colors:—

Color.	Parts Copper.	Parts Zinc.	Parts Iron.
Yellow	82.33	16.69	0.16
Pale green	84.32	15.02	0.63
Lemon	84.50	15.30	0.07
Copper-red	99.90	—	—
Orange	98.93	0.73	—
Pale yellow	90.00	9.60	—
Crimson	98.22	0.50	0.56

The better qualities of English bronze powders consist of copper 83 parts, silver 4.5, tin 8, oil 4.5, and the poorer qualities, of copper 64.8 parts, silver 4.3, tin 8.7., zinc 12.9, and oil 3.

The variety of bronze powder known under the name of "*brocade*," consists of coarser pieces prepared from the

waste of metal-leaf factories by comminuting it by means of a stamping-mill, and separating the pieces of unequal size formed, first by passing through a sieve, and finally by a current of air. A certain kind of brocade, however, does not consist of a metallic alloy, but simply of mica rubbed to a fine powder. Some kinds of bronze powder, as previously mentioned, are colored with aniline colors. This is effected by simply pouring a dilute solution of the aniline color in strong alcohol over the powder and intimately mixing.

Bronze powders from alloys of copper with 5 to 10 per cent. aluminium and 0.04 to 0.1 per cent. bismuth are, according to Lehmann, prepared directly from the block of metal by a cutting-machine, heating and boiling the powder, again heating several times, rubbing, washing, drying, sifting, and polishing between rolls. As a polishing agent for bronze powders Rosenhaupt uses mercurous nitrate.

Metallic powders are now directly produced electrolytically, several methods for this process having been patented in France and Germany.

WHITE BRASS.

Alloys of copper and zinc containing less than 45 per cent. of copper cease, as previously mentioned, to have a yellow color, the latter being, according to the content of zinc either pure white (silver white) or a pale, but pleasing, yellow. The ductility decreasing considerably with the increase in the content of zinc, such alloys cannot be used for rolling and wire-drawing, but they may be employed for castings which are to be finished by the lathe or file. Being quite cheap they are well adapted for casting statuettes and other small articles not exposed to the weather. In the air these alloys do not acquire the beautiful color of bronze known as patina, but a dirty brown-green.

On account of their white color some of these alloys are used for pressed work, such as buttons, etc., but only a moderate pressure can be applied.

Birmingham platinum or platinum-lead.—This alloy is of a pure, nearly silver-white color, which remains constant in the air for some time. It is, however, so brittle as to be only suitable for casting. Buttons are made of it by casting it in moulds giving sharp impressions, the letter, escutcheon, etc., upon the button being subsequently brought out more by careful pressing. The composition of the alloy varies according to the taste of the manufacturers as shown by the following examples:

	I.	II.	III.	
Copper	43.0	46.5	20	Parts.
Zinc	57.0	53.5	80	

Other alloys for white buttons consist of:

	I.	II.	III.	IV.	V.	
Copper	54.0	50.0	60.0	60.0	54.5	Parts.
Zinc	43.0	45.0	33.5	30.0	45.5	
Tin	3.0	5.0	6.5	10.0	—	

Sorel's alloy.—This important and valuable alloy possesses properties rendering it especially suitable for many purposes. It is chiefly remarkable for its considerable hardness, it being in this respect at least equal to good wrought-iron. Its toughness surpasses that of the best cast-iron. In casting it shows the valuable property of being readily detached from the mould, and it can be mechanically worked with great ease, but it is too brittle to be rolled out into sheets or drawn into wire. It is much used for casting small statues, which after careful bronzing are brought into commerce under the name of cast-bronze. It may also be employed in the manufacture of articles exposed to the influence of the weather, as it rusts with difficulty and finally becomes coated with a thin, firmly-adhering layer of oxide which prevents further oxidation. The following mixtures have nearly the same properties, though they vary very much as regards their composition:—

	Parts.	
Copper	1	10
Zinc	98	80
Iron	1	10

The iron is used in the shape of cast-iron shavings, which are added to the zinc. The copper is then added and the alloy kept for some time fluid under a cover of glowing coals, in order to insure an intimate combination of the metals without a combustion of the zinc. The alloy being difficult to prepare in the above manner on account of the combustibility of the zinc, it is recommended in preparing large quantities not directly to mix the metals, but to use brass of known composition. This is melted down under a cover of charcoal and slightly overheated; the zinc is then added, and finally the iron.

Bath-metal.—This alloy is used for the manufacture of candlesticks, tea-pots, buttons, etc., and is much liked on account of its beautiful yellowish-white to almost white color. It takes a high degree of polish, and articles manufactured from it acquire in the course of time a lasting silver luster by simply rubbing them with a soft cloth, Bath-metal is composed of:

Brass 32 parts and zinc 9 = copper 55 parts and zinc 45.

Guettier's button metals:—

1. Brass 372 (copper 297, zinc 93) zinc 62, tin 31.
2. " 372 (" 297, " 93) " 47, " 47.
3. " 372 (" 297, " 93) " 140, —

These alloys possess a silver color, No. 1 being the finest quality, No. 2, medium, and No. 3 inferior.

Ordinary English white metal.—Brass (copper 360, zinc 120) 480 parts, zinc 45, tin 15.

Fontainemoreau's bronzes.—These alloys are claimed to be well adapted for chill-casting, the metal being poured into iron moulds, whereby the alloys become more homo-

geneous, separation of the constituents being prevented by the rapid cooling. By the addition of copper, iron and lead, the highly crystalline nature of the zinc is changed. Examples of the composition of these so-called bronzes are given below:

	Parts.							
	I.	II.	III.	IV.	V.	VI.	VII.	VIII.
Zinc.....	90.00	91.0	92.0	92.0	97.0	97.0	99.0	99.5
Copper.....	8.0	8.0	8.0	7.0	2.5	3.0	1.0	—
Cast iron...	1.0	—	—	1.0	0.5	—	—	0.5
Lead	1.0	1.0	—	—	—	—	—	—

The preceding alloys are those which, strictly speaking, belong to the brasses, the composition of the mixtures as regards their principal constituents—copper and zinc—varying only within certain limits, and the addition of tin, lead, and iron being only made in order to change the properties of the alloys for certain purposes. Besides these alloys there are, however, some which find special application, and for that reason will be discussed separately; the alloys known as white metal, etc., belonging to this group.

In the following table, originally collated for the Committee on Alloys of the U. S. Board,* the properties of the alloys of copper and zinc as described by the best authorities are exhibited in a concise manner:—

* Report, Vol. II., 1881.

Properties of the Alloys of Copper and Zinc.—Comparison of several authorities.

Atomic formula.	Composition of original mixture.		Composition by analysis.		Specific gravity.	Color.	Fracture.	Tenacity, pounds per square inch.	Order of ductility (Mallet).	Relative ductility (Thurston).	Order of malleability (Mallet).	Hardness (Mallet, and Calvert and Johnson).	Order of fusibility (Mallet).	Conductivity for heat, silver=100.	Conductivity for electricity, silver=100.	Authority.	Remarks.
	Cu.	Zn.	Cu.	Zn.													
	100	0	—	—	8.874	Red	Fibrous	27.700	8	30.8	—	—	—	—	—	U.S.B.	
	100	0	—	—	8.667	Tile-red	Earthy	55.104	—	—	1	22	15	—	—	Ml.	
	100	0	—	—	8.921	—	—	—	—	—	—	—	—	—	93 16	Ma.	
	100	0	—	—	—	—	—	—	—	—	—	30.1	—	81.1	—	C. J.	
	100	0	—	—	8.952	—	—	—	—	—	—	—	—	—	—	Mar.	Sheet copper.
	100	0	—	—	—	—	—	—	—	—	—	—	—	73.6	79.3	We.	
	100	0	—	—	8.672	—	—	24.252	—	—	—	—	—	—	—	We.	Mean of 9 samples.
	99.15	0.85	—	—	—	—	—	—	—	—	—	—	—	—	—	Bo.	Tombac for buttons.
	97.80	2.20	—	—	—	—	—	—	—	—	—	—	—	—	—	—	Red tombac of Vienna.
	97.50	2.50	97.83	1.88	8.791	Yellow-red	Vesicular	27.240	—	118.9	—	—	—	—	—	U.S.B.	
	97.50	2.50	—	—	—	—	—	—	—	—	—	—	—	—	—	Bo.	Railway axles, porous.
	95	5	96 07	3.79	8.825	Yellow-red	Vesicular	11.500	—	37.9	—	—	—	—	—	U.S. B.	Defective bar.
	93.6	6.4	—	—	—	—	—	—	—	—	—	—	—	—	—	Bo.	Pinchbeck.
	92.5	7.5	92.32	7.68	8.746	Yellow-red	Vesicular	—	—	—	—	—	—	—	—	U.S.B.	
	92.5	7.5	—	—	—	—	—	—	—	—	—	—	—	—	—	Bo.	Bearings, Austria.
	92	8	—	—	—	—	—	—	—	—	—	—	—	—	—	Bo.	Red tombac of Paris.
	91	9	—	—	—	—	—	—	—	—	—	—	—	—	—	Bo.	Tombac.
$Cu_{10}Zn$	90.72	9.28	—	—	8.605	Red-yellow	Coarsely crystalline	27.104	6	—	13	21	14	—	—	Ml.	
$Cu_{10}Zn$	90.65	9.35	—	9.60	8.834	—	—	—	—	—	—	—	—	—	—	Ri.	Specific gravity of ingot,
	90	10	90.56	9.42	8.773	Yellow-red	Vesicular	—	—	169.1	—	—	—	—	—	U.S.B.	[8.753.
	90	10	—	—	—	—	—	—	—	—	—	—	—	—	—	Bo.	French oröide.
Cu_9Zn	89.80	10.20	—	—	8.607	Red-yellow	Finely crystalline	25.760	4	—	11	20	13	—	—	Ml.	
	88.89	11.11	—	—	—	—	—	—	—	—	—	—	—	27.3	25.5	We.	
Cu_8Zn	88.60	11.40	—	—	8.633	Red-yellow	Finely crystalline	28.672	2	—	10	19	12	—	—	Ml.	
	87.50	12.50	88.94	10.97	—	Yellow-red	Vesicular	—	—	—	—	—	—	—	—	U.S.B.	
Cu_7Zn	87.30	12.70	—	—	8.587	—	Finely crystalline	29.568	9	—	9	18	11	—	—	Ml.	
	86.67	13.33	—	—	—	—	—	—	—	—	—	—	—	29.9	30.9	We.	
	86.38	13.61	—	—	—	—	—	—	—	—	—	—	—	—	—	Bo.	Very delicate castings.
	86	14	—	—	—	—	—	—	—	—	—	—	—	—	—	Bo.	Ornaments of Hanover.
	85.5	14.5	—	—	8.591	Yellow-red	Fine fibrous	31.584	5	—	8	17	10	—	—	Bo.	French oröide.
Cu_6Zn	85.34	14.66	—	14.90	8.710	—	—	—	—	—	—	—	—	—	—	Ml.	
	85.3	14.7	—	—	—	—	—	—	—	—	—	—	—	—	—	Ri.	Specific gravity of pow-
	85	15	89.80	10.06	8.656	Red-yellow	Earthy	—	—	250.1	—	—	—	—	—	Bo.	Paris jewelry. [der, 8.584.
	85	15	—	—	—	—	—	—	—	—	—	—	—	—	—	U.S.B.	
	81.6	15.4	—	—	—	—	—	—	—	—	—	—	—	—	—	Bo.	Tombac of Oker.

Properties of the Alloys of Copper and Zinc.—Continued.

Atomic formula.	Composition of original mixture.		Composition by analysis.		Specific gravity.	Color.	Fracture.	Tenacity, pounds per square inch.	Order of ductility (Mallet).	Relative ductility (Thurston).	Order of malleability (Mallet).	Hardness (Mallet, and Calvert and Johnson).	Order of fusibility (Mallet).	Conductivity for heat, silver = 100.	Conductivity for electricity, silver = 100.	Authority.	Remarks.
	Cu.	Zn.	Cu.	Zn.													
	84.21	15.79	—	—	—	—	—	—	—	—	—	—	—	—	—	Bo.	Gold leaf.
	83.99	17.1	—	—	—	—	—	—	—	—	—	—	—	—	—	Bo.	Tombac for buttons.
Cu_5Zn	83.02	16.98	—	—	8.415	Red-yellow	Finely crystalline	30.688	11	—	2	16	9	—	—	Bo.	Bronze powder.
Cu_5Zn	82.95	17.05	—	—	8.673	—	—	—	—	—	—	427.08	—	71.5	—	Ml	Bath metal.
	82.54	17.46	—	—	—	—	—	—	—	—	—	—	—	—	—	C. J.	
	82.5	17.5	82.93	16.98	8.633	Red-yellow	Earthy	32.600	—	105.3	—	—	—	—	—	Bo.	Alloy for jewelry.
	82.46	17.54	—	—	—	—	—	—	—	—	—	—	—	31.1	24.02	U.S.B.	
	82.3	17.7	—	—	—	—	—	—	—	—	—	—	—	—	—	We.	
	80	20	81.91	17.90	8.598	Yellow	Earthy	32.670	—	113.1	—	—	—	—	—	Bo.	Ornaments.
Cu_4Zn	79.65	20.35	—	—	—	Yellow-red	Finely crystalline	32.928	7	—	3	15	8	—	—	U.S.B.	
Cu_4Zn	79.56	20.44	—	—	8.650	—	—	—	—	—	—	468.75	—	66.6	—	Ml.	Dutch brass.
Cu_4Zn	79.51	20.49	—	21.80	8.638	—	—	—	—	—	—	—	—	—	—	C. J.	[der, 8.367.
	77.9	22.1	—	—	—	—	—	—	—	—	—	—	—	—	—	Ri.	Specific gravity of pow-
	77.5	22.5	77.39	22.45	8.574	Yellow	Earthy	35.630	—	97.5	—	—	—	—	—	Bo.	Vienna gold leaf.
	75.7	24.3	—	—	—	—	—	—	—	—	—	—	—	—	—	U.S.B.	
	75	25	76.65	23.08	8.528	Yellow	Earthy	30.520	—	76.7	—	—	—	—	—	Bo.	Bristol metal.
	74.62	25.38	—	—	—	—	—	—	—	—	—	—	—	—	—	U.S.B.	
Cu_3Zn	74.58	25.42	—	—	8.397	Pale yellow	Finely crystalline	29.344	10	—	4	14	7	—	—	Ml.	Rolled sheet brass.
Cu_3Zn	74.48	25.52	—	—	8.576	—	—	—	—	—	—	468.75	—	63.8	—	C. J.	Brass of 32 copper, 12 zinc.
	72.73	27.27	—	—	—	—	—	—	—	—	—	—	—	—	—	Bo.	
	72.5	27.5	73.20	26.47	8.465	Yellow	Earthy	31.580	—	88.7	—	—	—	—	—	U.S.B.	
	72	28	—	—	—	—	—	—	—	—	—	—	—	—	—	Bo.	Chrysorin.
	71.5	28.5	—	—	—	—	—	—	—	—	—	—	—	—	—	Bo.	Tombac.
	70.1	29.9	—	—	—	—	—	—	—	—	—	—	—	—	—	Bo.	Suitable for forging or
	70	30	71.20	28.54	8.444	Yellow	Earthy	30.510	—	77.8	—	—	—	—	—	U.S.B.	[leaf.
	67.74	32.26	—	—	—	—	—	—	—	—	—	—	—	25.8	25.4	We.	
	67.54	32.46	—	—	—	—	—	—	—	—	—	—	—	—	—	Bo.	Suitable for forging.
	67.5	32.5	69.74	30.06	8.384	Yellow	Earthy	28.120	—	49.1	—	—	—	—	—	U.S.B.	
	67.2	32.8	—	—	—	—	—	—	—	—	—	—	—	—	—	Bo.	Bristol metal.
	66.7	33.3	—	—	—	—	—	—	—	—	—	—	—	—	—	Bo.	Chrysorin.
	66.6	33.4	—	—	—	—	—	—	—	—	—	—	—	—	—	Bo.	Common brass.
Cu_2Zn	66.18	33.82	—	—	8.299	Full yellow	Finely crystalline	28.000	3	—	6	13	6	—	—	Ml.	
Cu_2Zn	66.16	33.84	—	—	8.492	—	—	—	—	—	—	—	—	—	—	Cr.	
Cu_2Zn	66.06	33.94	—	—	8.48	—	—	—	472.92	—	—	—	—	62.1	—	C. J.	
	66	34	—	—	—	—	—	—	—	—	—	—	—	—	—	Bo.	Suitable for forging.

Properties of the Alloys of Copper and Zinc.—Continued.

Atomic formula.	Composition of original mixture.		Composition by analysis.		Specific gravity.	Color.	Fracture.	Tenacity, pounds per square inch.	Order of ductility (Mallet).	Relative ductility (Thurston).	Order of malleability (Mallet).	Hardness (Mallet, and Calvert and Johnson).	Order of fusibility (Mallet).	Conductivity for heat, silver=100.	Conductivity for electricity, silver=100.	Authority.	Remarks.
	Cu.	Zn.	Cu.	Zn.													
	65.98	34.02	—	31.50	8.410	——	——	—	—	—	—	—	—	—	—	Ri.	Specific gravity of powder.
	65.4	34.6	—	—	—	——	——	—	—	—	—	—	—	—	—	Bo.	Good brass wire. [8.390.
	65.3	34.7	—	—	—	——	——	—	—	—	—	—	—	—	—	Bo.	Mosaic gold.
	65	35	66.27	33.50	8.371	Red-yellow	Earthy	37.800	—	72.8	—	—	—	—	—	U.S.B.	
	65	34 76	—	—	—	——	——	—	—	—	—	—	—	—	—	Bo.	Suitable for forging.
	63.5	36.5	—	—	—	——	——	—	—	—	—	—	—	—	—	Bo.	" " "
	62.5	37.5	63.41	36.36	8.411	Red-yellow	Earthy	48.700	—	60.6	—	—	—	—	—	U.S.B.	
	61.25	38.75	—	—	—	——	——	—	—	—	—	—	—	—	—	Bo.	Strong solder for brass.
	60.8	39.2	—	—	—	——	——	—	—	—	—	—	—	—	—	Bo.	Bristol metal.
	60 16	39.71	—	—	—	——	——	—	—	—	—	—	—	—	—	Bo.	Suitable for forging.
	60	40	60.94	38.65	8.405	Red-yellow	Earthy	41.065	—	49.0	—	—	—	—	—	U.S.B.	
	60	40	—	—	—	——	——	—	—	—	—	—	—	—	—	—	Muntz metal.
	59.5	40.5	—	—	—	——	——	—	—	—	—	—	—	—	—	Bo.	Ship sheathing.
Cu_2Zn_2	59.36	40.64	—	—	8.224	——	——	—	—	—	—	—	—	—	—	Cr.	[der, 8.329.
Cu_2Zn_2	59. 6	40.74	—	40.10	8.412	——	——	—	—	—	—	—	—	—	—	Ri.	Specific gravity of pow-
	58.33	41.77	—	—	—	——	——	—	—	—	—	—	—	—	—	Bo.	Su table for forging.
	57.5	42.5	58.49	41.10	8.363	Red-yellow	Earthy	50.450	—	12.1	—	—	—	—	—	U.S.B.	
	55	45	—	—	—	——	——	—	—	—	—	—	—	—	—	Bo.	Bath metal.
	55	45	55.15	44 44	8.283	Red-yellow	Earthy	44.280	—	19.5	—	—	—	—	—	U.S.B.	
	54.9	45.1	—	—	—	——	——	—	—	—	—	—	—	—	—	Bo.	Very ductile brass(Storer).
	54	46	—	—	—	——	——	—	—	—	—	—	—	—	—	Bo.	" " "
	52.5	47.5	51.86	44.78	8.301	Red-yellow	Coarsely granular	46.400	—	7.4	—	—	—	—	—	U.S.B.	
	50	50	49.66	50.14	8.291	"	"	30.990	—	3.1	—	—	—	—	—	U.S.B.	
CuZn	49.47	50.53	—	—	8.230	Full yellow	Coarsely crystalline	20 608	12	—	5	12	6	—	—	Ml.	German brass.
CuZn	49.32	50.68	—	—	7.808	——	——	—	—	—	—	C01.17	—	68.8	—	C. J.	
CuZn	49.23	50.76	—	50.30	8 301	——	——	—	—	—	—	—	—	—	—	Ri.	Specific gravity of ingot.
	47.5	52.5	48.95	50.82	8.216	Pinkish-gray	Coarsely granular	26.050	—	0.36	—	—	—	—	—	U.S.B.	[8.265.
	45	55	47.56	52.28	—	"	"	24. 50	—	0.26	—	—	—	—	—	U.S.B.	
	43	57	—	—	—	——	——	—	—	—	—	—	—	—	—	Bo.	Escutcheons of locks.
	42.5	57.5	43.36	56.22	8.034	Pinkish-gray	Finely granular	9 710	—	0.02	—	—	—	—	—	U.S.B.	
	40	60	41.30	58.12	8.061	Silver-white	Vitreous conchoidal	3.727	—	0.01	—	—	—	—	—	U.S.B.	
Cu_2Zn_3	39.27	60.73	—	60.35	8.171	——	——	—	—	—	—	—	—	—	—	Ri.	Specific gravity of ingot,
	37.5	62.5	38.36	61.05	7.982	Silver-white	Vitreous conchoidal	3.087	—	0.02	—	—	—	—	—	U.S.B.	[8.039.
Cu_3Zn_5	36.88	63.12	—	—	7.939	——	——	—	—	—	—	—	—	—	—	Cr.	
	35	65	36.62	62.78	7.974	Silver-white	Vitreous conchoidal	2.656	—	0.006	—	—	—	—	—	U.S.B.	

Properties of the Alloys of Copper and Zinc.—Concluded.

Atomic formula	Composition of original mixture.		Composition by analysis.		Specific gravity.	Color.	Fracture.	Tenacity, pounds per square inch.	Order of ductility (Mallet).	Relative ductility (Thurston).	Order of malleability (Mallet).	Hardness (Mallet, and Calvert and Johnson).	Order of fusibility (Mallet).	Conductivity for heat, silver = 100.	Conductivity for electricity, silver = 100.	Authority.	Remarks.
	Cu.	Zn.	Cu.	Zn.													
$CuZn_2$	33.34	66.66	—	—	—	——	——	—	—	—	—	—	—	—	—	Bo.	Strong solder for brass.
$CuZn_2$	32.85	67.15	—	—	8 283	Deep yellow	Coarsely crystalline	43.232	1	—	7	10	6	—	—	Ml.	Watchmaker's brass.
$CuZn_2$	32.74	67.26	—	—	7.859	——	——	—	—	—	—	Broke	—	42.8	—	C. J.	
$CuZn_2$	32.65	67.34	—	64.80	8.048	——	——	—	—	—	—	—	—	—	—	Ri.	Specific gravity of ingot, [7.796.
	32.5	67.5	35.68	63.71	7.966	Silver-white	Vitreous conchoidal	2.397	—	0.11	—	—	—	—	—	U.S.B.	
Cu_8Zn_{17}	31.52	68.48	—	—	7.721	"	Conchoidal	4.704	0	—	22	5	5	—	—	Ml.	Very brittle.
Cu_8Zn_{18}	30 30	69.70	—	—	7.846	"	Vitreous conchoidal	4.928	0	—	23	6	5	—	—	Ml.	Very brittle.
	30	70	32.94	66.23	7 811	"	"	1.774	—	0.005	—	—	—	—	—	U.S.B.	
Cu_8Zn_{19}	29.17	70.83	—	—	8.019	Silver-gray	Conchoidal	1.568	0	—	21	7	5	—	—	Ml.	Very brittle.
Cu_8Zn_{20}	28.12	71.88	—	—	7. 03	Ash-gray	Vitreous	7.168	0	—	19	3	5	—	—	Ml.	Brittle.
	27.5	72.5	29 20	70.17	7.766	Light gray	"	6.414	—	0.009	—	—	—	—	—	U.S.B.	
Cu_8Zn_{21}	27.10	72 90	—	—	8 058	Silver-gray	Conchoidal	2.016	0	—	18	9	5	—	—	Ml.	Brittle.
Cu_8Zn_{22}	26.21	73.76	—	—	7.882	"	"	1.792	0	—	20	8	5	—	—	Ml.	Very brittle.
	25.4	74.6	—	—	—	——	——	—	—	—	—	—	—	—	—	Bo.	Protects iron from rust.
Cu_8Zn_{23}	25.39	74.61	—	—	7.443	Ash-gray	Finely crystalline	13.216	0	—	15	1	5	—	—	Ml.	Barely malleable.
	25	75	—	—	7.675	Bluish-gray	Finely granular	9.680	—	0.002	—	—	—	—	—	U.S.B.	
$CuZn_3$	24.61	75.36	—	—	7.736	——	——	—	—	—	—	Broke	—	53.1	—	C. J.	
$CuZn_3$	24.5	75.5	—	—	7.419	Ash-gray	Finely crystalline	11.424	0	—	16	2	4	—	—	Ml.	Brittle.
	22.5	77.5	21.82	77.43	7.416	Bluish-gray	Finely granular	7 000	—	0.001	—	—	—	—	—	U.S.B.	
	20	80	20.81	77 63	7.418	"	"	9.000	—	0.002	—	—	—	—	—	U S.B.	
	20	80	—	—	—	——	——	—	—	—	—	—	—	—	—	Bo.	Metal for buttons.
$CuZn_4$	19.65	80 35	—	—	7.371	Ash-gray	Finely crystalline	4.256	0	—	14	4	3	—	—	Ml.	White button metal.
$CuZn_4$	19.57	80.43	—	—	7.445	——	——	—	—	—	—	Broke	—	58.9	—	C. J.	
$CuZn_4$	19.52	80.48	—	79.30	7.863	——	——	—	—	—	—	—	—	—	—	Ri.	Specific gravity of ingot, [7.215.
	17.5	82.5	17.49	81.62	7.225	Bluish-gray	Finely granular	5.350	—	0.003	—	—	—	—	—	U.S.B.	
$CuZn_5$	16.36	83.64	—	—	6. 05	Verydark gray	Finely crystalline	4.032	0	—	17	11	2	—	—	Ml.	Brittle.
$CuZn_5$	16.30	83.70	—	—	7 442	——	——	—	—	—	—	Broke	—	59.5	—	C. J.	
	15	85	14.19	85 10	7.163	Bluish-gray	Finely granular	8.500	—	0.001	—	—	—	—	—	U.S.B.	
	12.5	87.5	12.12	86.67	7.238	"	"	12.413	—	0.009	—	—	—	—	—	U.S.B.	
$CuZn_8$	10.82	89.18	—	89.90	7.315	——	——	—	—	—	—	—	—	—	—	Ri.	Specific gravity of ingot, [7.299.
	10	90	10.30	88 88	7.253	Bluish-gray	Finely granular	14.450	—	0.10	—	—	—	—	—	U.S.B.	
	7 5	92.5	7.20	92 07	7.131	"	"	10.650	—	8.14	—	—	—	—	—	U.S.B.	
	5	95	4.35	94.59	7.108	"	Finely crystalline	18.065	—	0.84	—	—	—	—	—	U.S.B.	
	2.5	97.5	2.45	96.43	7.080	"	Tabular crystalline	11.400	—	2.67	—	—	—	—	—	U.S.B.	
	0	100	—	—	7.143	Bluish-white	"	5.400	—	26.51	—	—	—	—	—	U.S.B.	
	0	100	—	—	6.895	Bluish-gray	"	34.018	13	—	12	23	1	—	—	Ml.	Brittle.
	0	100	—	—	7.148	——	——	—	—	—	—	—	—	29.02	27.39	Ma.	
	0	100	—	—	—	——	——	—	—	—	—	—	—	62.8	—	C. J.	
	0	100	—	—	—	——	——	—	—	—	—	—	—	28.1	27.3	We.	

LIST OF AUTHORITIES.

Bo.—Bolley. *Essais et Recherches Chimiques*, Paris, 1869.
Cr.—Croockewit. *Erdmann's Journal*, XLV. 1848, pp. 87 to 93.
C. J.—Calvert and Johnson. *Phil. Mag.*, 18, 1850, pp. 354 to 359; *ibid.*, 17, 1859, pp. 114 to 121; *ibid.*, 16, 1858, pp. 381 to 383.
Ma.—Matthiessen. *Phil. Trans.*, 1860, pp. 161 to 184; *ibid.*, 1864, pp. 167 to 200.
Ml.—Mallet. *Phil. Mag.*, Vol. 21, 1842, pp. 66 to 68.
Ri.—Riche. Annales de Chimie, 30, 1873, pp. 351 to 410.
U. S. B.—Report of Committee on Metallic Alloys of United States Board appointed to test iron, steel, etc. (Thurston's Investigations.)
We.—Weidemann. *Pogg. Annalen*, 108, 1859, pp. 393 to 407.

Prof. Robert H. Thurston, who conducted the investigations of the United States Board, makes the following note on the preceding table:

"Alloys having the name of Bolley appended are taken from Bolley's 'Essais et Recherches Chimiques,' which gives compositions and commercial names, and mentions valuable properties, such as are given in the columns of remarks, but does not give results in figures as recorded by other authorities. The same properties and the same names are accorded by Bolley to alloys of different compositions, such as those which in the column of remarks are said to be 'suitable for forging.' It might be supposed that such properties belonged to those mixtures and not to other mixtures of similar composition. It seems probable, however, that when two alloys of different mixtures of copper and zinc are found to have the same strength, color, fracture, and malleability, it will also be found that all alloys between these compositions will possess the same properties, and hence that instead of the particular alloys mentioned only being suitable for forging, all the alloys between the extreme compositions mentioned also possess that quality.

"In the figures given from Mallet under the heads of 'order of ductility,' 'order of malleability,' 'hardness,' and 'order of fusibility,' the maximum of each of these properties is represented by 1.

"The figures given by Mallet for tenacity are confirmed

by experiments of the author with a few very marked exceptions. These exceptions are chiefly the figures for copper, for zinc, and for $CuZn_2$ (32.85 copper, 67.15 zinc). The figures for $CuZn_2$, as given by Mallet, can, in the opinion of the author, only be explained on the supposition that the alloy tested was not $CuZn_2$ (32.85 copper, 67.15 zinc), but another containing a percentage of copper probably as high as 55. The figure for the specific gravity (8.283) given by Mallet indicates this to be the case as does the color. The figure for ductility would indicate even a higher percentage of copper. The name 'watchmaker's brass' in the column of remarks must be an error, as that alloy is a brittle, silver-white, and extremely weak metal.

"The figures of Calvert and Johnson and Riche, as well as those of the author, give a more regular curve than can be constructed from the figures of Mallet.

"The specific gravities in Riche's experiments were obtained both from the ingot and from powder. In some cases one, and in some cases the other, gave highest results. In the table under the head of 'specific gravity,' Riche's highest average figures are given, whether these are from the ingot or from fine powder, as probably the most nearly correct. The figures by the other method, in each case, are given in the column of remarks. The figures of Riche, and Calvert and Johnson are scarcely sufficient in number to show definitely the law regulating specific gravity to composition, and the curves from their figures vary considerably. The figures of the author being much more numerous than those of earlier experimenters, a much more regular curve is obtained, especially in that part of the series which includes the yellow or useful metals. The irregularity in that part of the curve which includes the bluish-gray metals is, no doubt, due to blow-holes, as the specific gravities were in all cases determined from pieces of considerable size. If they were determined from powder,

it is probable that a more regular set of observations could be obtained, and that these would show a higher figure than 7.143, that obtained for cast-zinc. Matthiessen's figure for pure zinc (7.148) agrees very closely with that obtained by the author for the cast-zinc, which contained about 1 per cent. of lead.

"The figures for hardness given by Calvert and Johnson were obtained by means of an indenting tool. The figures are on a scale in which the figure for cast-iron is taken as 1000. The alloys, opposite which the word "broke" appears, were much harder than cast-iron, and the indenting tool broke them instead of making an indentation. The figures of alloys containing 17.05, 20.44, 25.52, and 33.94 per cent. of zinc have nearly the same figures for hardness, varying only from 427.08 to 472.92. This corresponds with what has been stated in regard to the similarity in strength, color and other properties of alloys between these compositions."

CHAPTER VII.

COPPER—TIN ALLOYS.

Bronze in General.

THE bronzes are the most celebrated of all the alloys. In ancient times, bronze already formed an important material for weapons, household utensils, and ornaments, and the opinion for a long time held by archæologists that among the early civilized people bronze was used for these purposes prior to iron gave rise to the term *bronze age* being applied to an entire period. This opinion is, however, now considered erroneous.*

However, the term bronze itself is not very old and seems to have first been introduced in the 15th or 16th century. The Italian author Vannuccio Biringoccio states in his "Pirotechnia," published in 1550, that alloys of copper and tin were termed *bronzo*, but fails to give the derivation of the word. From the Italian the term passed into the English, French, German, and other languages. Whether the opinion expressed by the French chemist Berthelot, that the alloy was originally called *brondision*, and that its name was derived from the city Brundusium (Brindisi), is correct, must be left undecided.

The term bronze is frequently erroneously applied to mixtures of metals belonging really to the brasses, so that there is actually such a confusion of terms that many whose interest it is to have an accurate knowledge of alloys do not know what bronze actually is.

In the widest sense, bronze may be designated as copper,

*Complete refutations of this opinion are found in Dr. L. Beck's "Geschichte des Eisens," vol. 1, pp. 35, 343, 580.

which by the absorption of other bodies, has become stronger and harder, and capable of being cast. The principal constituent of bronze, therefore, in all cases, is copper, the addition of tin only serving to modify its properties. Tin, though a rather soft metal by itself, possesses, as previously mentioned, the characteristic property of imparting great hardness to copper, so that genuine bronze takes a fine polish, and castings of it can be worked very clean with the file. On account of these qualities it is especially adapted for a casting material, and its properties can be so changed that it will flow freely, or give a beautiful sound, or acquire the utmost degree of hardness.

The ductility of bronze being but slight, only that containing very little tin can be converted into sheet by rolling, the operation succeeding satisfactorily at a red heat if the content of tin does not exceed 4 to 6 per cent. Bronze, as previously mentioned, being chiefly intended for casting, finds, on account of its hardness, much application in the machine industry for articles which cannot be made of iron or steel.

Bronzes consisting of absolutely pure copper and tin show definite properties according to the quantity of the metals contained in them. However, in making a chemical analysis of commercial bronze, it will almost invariably be found to contain a small quantity of other metals. A sharp distinction should, however, be made as to whether these admixtures are accidental or intentional. Besides iron, manganese, nickel, lead, and zinc, very small quantities of phosphorus, arsenic, sulphur, or antimony, are sometimes found, and as a small quantity of these bodies suffices to considerably change the properties of the alloy, it is important to pay some attention to their influence. Before entering on a discussion of these properties, it may, however, be remarked that the difficulties many manufacturers find in obtaining alloys of determined qualities is due to the fact that they do not use as pure metals as possible by

themselves, but melt down with them certain quantities of old bronze, which, as a rule, contains zinc, iron, or other foreign metals.

A content of zinc acts upon the properties of bronze in various ways. Added to it in a very small quantity it has even a beneficial influence, the moulds being filled out sharper and the castings obtained freer from blow-holes. If, however, the addition of zinc be exceeded above a certain limit, the alloy loses the characteristic properties of bronze, and especially the warm color, which passes into a more or less dull brass yellow. Besides, bronze with too large a content of zinc does not acquire on exposure to the air the beautiful green coloration termed genuine patina, but one shading into black. The addition of zinc must always be kept within very narrow limits, less than one-half per cent. of it contributing so essentially to the strength of the bronze that such an addition should be made in all cases where this property is especially desired. With an addition of up to 2 per cent. of zinc the properties of the alloy remain about the same, its elasticity being also increased to a considerable extent. With a slight increase of over 2 per cent. of zinc, the hardness as well as the tenacity of the bronze decreases to a considerable extent, and the brass-like character of the alloy soon becomes apparent.

An admixture of lead has in all cases an injurious effect upon the properties of bronze. With a content of one-half per cent. the lead begins to liquate from the bronze, which makes the castings turn out unequal, and increases the oxidability of the alloy. A content of lead makes the bronze somewhat denser and more malleable, these properties being, however, of little value, as the alloy is exclusively intended for casting. The peculiar patina of a velvety-black color found upon old Chinese bronzes is said to be the product of a content of lead; and it is actually a fact that all Chinese bronzes contain a certain quantity of lead.

Iron affects the properties of bronze in a manner similar to zinc, imparting great hardness to it, and for this reason is frequently added to bronzes for axle-bearings and wherever they are to show great power of resistance. A content of iron has also considerable influence upon the color and gives a peculiar white tone to the bronze. It further makes it more difficult of fusion, though the castings are faultless.

An admixture of nickel increases the hardness of bronze to a considerable extent and decreases its toughness. On account of its costliness many declared the use of this metal as an addition to bronze impracticable. It must, however, not be forgotten that at the utmost only 1 to 1½ per cent. of it are required to impart the desired qualities. Moreover it is not by any means the most expensive metal used as an addition to bronze, tungsten and titanium being also frequently employed for the purpose. These last-mentioned metals seem, however, to possess no special properties exerting a favorable influence upon bronze, and, though the alloys have been frequently mentioned and recommended in various periodicals, they have not gained a foothold in practice, which cannot be ascribed to their costliness, because manufacturers requiring alloys completely answering certain purposes, are always willing to pay a good price for them.

An admixture of very small quantities of arsenic, antimony, and sulphur, renders the bronze brittle, $\frac{1}{10}$ per cent. of either of these bodies sufficing for the purpose. Phosphorus exerting, as is well known, an injurious influence upon most metals and alloys, acts differently in this respect as regards bronze, and, for this reason, the so-called phosphor-bronze will be discussed later on.

The physical properties of bronze are also materially affected by other conditions than the chemical composition, chief among which is the rapid or slow cooling off of the fused material, which exerts so powerful an influence that

the product with an equal chemical composition may acquire an entirely different appearance. According to the content of tin the color of bronze varies between red and white, and with a considerable content of tin passes into steel-gray. Generally speaking, tin exerts a greater influence upon the color than zinc, the alloy with a comparatively small content of tin exhibiting no longer a red, but a white, color.

Alloys containing 90 to 99 per cent. of copper retain a pure red color; with 88 per cent. of copper it rapidly changes to orange-yellow, and with 85 per cent. becomes pure yellow. With a decrease of the content of copper to 50 per cent. the respective alloys show a slightly yellowish-white color. It is a remarkable fact that alloys with a content of copper of between 50 and 35 per cent., are distinguished by a pure white color, while those containing up to 65 per cent. of tin show a steel-gray color. With a still greater percentage of tin the color of the alloys again becomes pure white. Bronze of various compositions being extensively used in the construction of machinery and the manufacture of ordnance, many physicists have occupied themselves with the determination of the proportions of ductility and hardness of the various alloys. But, notwithstanding the many full researches, it cannot yet be said with absolute certainty when a bronze is hardest, toughest, most ductile, etc., and we have only approximate numbers for these proportions, which may briefly be summed up as follows:

Alloys with 1 to 2 per cent. of tin show nearly the same ductility as pure copper; they can be worked in the cold under the hammer, but crack more readily than pure copper, this cracking showing itself especially in attempting to stretch a plate of the alloy under the hammer. The ductility decreases rapidly with an increase in the content of tin; an alloy containing 5 per cent. of tin can only be worked with the hammer at a red heat, but soon cracks

when it is attempted to hammer it in the cold; alloys containing up to 15 per cent. of tin can no longer be hammered even in a warm state. The figures above given show that tin reduces the ductility of the copper. Its solidity is, however, considerably increased. Alloys with about 9 per cent. of tin show, according to most statements, the greatest strength of all bronzes, and in accordance with this, gun-metal has generally a content of tin approaching that limit. According to other statements alloys with about 15 per cent. possess the greatest hardness and strength. The maximum for hardness and brittleness lies between a content of 28 and 35 per cent. of tin.

From the results of more modern researches in regard to the strength and hardness of bronzes, the following may be deduced: The hardness increases constantly until the composition of the alloy has reached 72.8 parts of copper and 27.2 of tin. With an increase in the content of tin the hardness decreases, it being, in a mixture of 33.33 parts of copper and 66.66 parts of tin, nearly exactly the same as that of pure copper. Above this proportion of tin the hardness decreases considerably, and with a compound of 90 parts of tin and 10 of copper is but little more than that of tin.

Alloys rich in copper undergo a peculiar molecular change by forging. By subjecting alloys containing somewhat less than 94 per cent. of copper to continued forging they become as hard as steel, but unfortunately acquire at the same time such a degree of brittleness that they can only be used for purposes where they are not exposed to heavy shocks.

Though the hardening of bronzes by forging is remarkable, there is another phenomenon yielding still more remarkable results. By quickly cooling off red-hot bronze in cold water it almost completely loses its brittleness, and can then be used for many purposes, an alloy containing 84 parts of copper and 16 of tin being most suitable for the purpose. Even a quite thick article acquires a certain

flexibility through its entire thickness, which it retains after forging. If it is desired to restore an article after tempering to its original hardness, it need only be brought to a red heat and slowly cooled. According to the above the behavior of bronze in this respect is just the reverse of that of steel, the latter by quick cooling becoming very hard and brittle, and by slow cooling soft and malleable. The density and hardness of bronze decrease with quick cooling and increase with slow cooling, and, hence, bronze articles quickly cooled have a deeper sound, a fact well to be considered by bell-founders.

The density and hardness, as well as the power of resistance against cracking, depend on the composition of the alloy as much as on the manner of cooling the cast articles.

According to practical experience the greatest strength is secured by endeavoring to obtain the crystals of the alloy as small as possible, even the material of the mould in which the casting is effected exerting a great influence upon the grain, and through this upon the strength. Articles must be cast at a higher temperature in iron moulds than in sand moulds, one of 2912° F. (1600° C.) being required with the use of iron moulds, while one of 2552° F. (1400° C.) suffices with the use of sand moulds, especially for larger castings.

Alloys suddenly subjected to a high pressure, as is the case with gun-metal, must have an especially high degree of density, the density being, however, not directly proportional to the composition, as will be seen from the following table:—

Composition.		Density.
Copper.	Tin.	
96.2	3.8	8.74
94.4	5.6	8.71
92.6	7.4	8.68
91.0	9.0	8.66
89.3	10.7	8.63
87.7	12.3	8.61
86.2	13.8	8.60
75.0	25.0	8.43
50.0	50.0	8.05

Bronze being exclusively used for casting, it is important to say a few words in regard to the temperatures at which the various alloys become fluid. According to Künzel, to whose researches we are indebted for much information regarding the properties of bronze, the various alloys show the following melting points:—

Composition.		Melting point, degrees F.	Melting point, degrees C.
Copper.	Tin.		
95	5	2520	1360
92	8	2354	1290
90	10	2282	1250
89	11	2228	1220
86	14	2100	1150
84	16	2012	1100
80	20	1868	1020

Articles cast of bronze contract in solidifying, as is the case with other mixtures of metals, the degree of contraction depending on the temperature of the alloy and its composition, and amounts to $\frac{1}{130}$ to $\frac{1}{77}$ of the bulk of the various mixtures.

The difficulty of obtaining perfect castings is, however,

more increased by the chemical behavior of the alloys towards the oxygen of the atmosphere than by contraction. In subjecting the bronze to fusion, the tin shows greater affinity for oxygen than the copper, and hence by remelting the bronze several times, it becomes sensibly richer in copper by a portion of the tin being lost by oxidation. To prevent a change in the qualities of the alloy, a larger quantity of tin than the finished product is to contain is generally added, so that the tin lost by volatilization is equal to the excess added, and the alloy obtained shows exactly the desired composition.

Another effect of the oxygen of the atmosphere consists in the oxides of the constituent metals of the bronze—stannic oxide and cuprous oxide—dissolving in the alloy, whereby its strength and toughness are considerably decreased. In the manufacture of ordnance a portion of the metal required is generally obtained by melting down old cannon. The mixture of metals thus obtained containing frequently large quantities of the metallic oxides in solution, the toughness and strength of the new alloys are considerably impaired.

The melted bronze shows another property frequently observed in other metals, especially in gold and silver: it can absorb a considerable quantity of oxygen, but allows it to escape in a gaseous state on cooling. If now, as is done in most cases, the castings are rapidly cooled off, the bronze becomes so thickly-fluid that the absorbed oxygen cannot escape, and the resulting castings are full of innumerable, though microscopically small, hollow spaces, which injure the density and strength of the alloy.

The absorption of oxygen, as will be seen from the above, being very injurious to the qualities of the bronze, precautions have to be taken to protect the metal from the effect of oxygen in fusing as well as in casting. The best preventative against the absorption of oxygen is to protect the alloy by a layer of glowing charcoal, and to effect a reduc-

tion of any oxides formed by vigorous stirring of the fused alloy with a stick of green wood. Though oxidation is counteracted by these means, it is not possible to remove by them the oxygen reaching the alloy from oxygenous material. Phosphorus has, however, been found an excellent agent for the deoxidation of the oxides dissolved in the metal, but it has to be added very carefully, since a small quantity of it in excess exerts great influence upon the properties of the alloy itself. In most cases an addition of $\frac{8}{1000}$ to $\frac{10}{1000}$ suffices for the reduction of the oxides in solution.

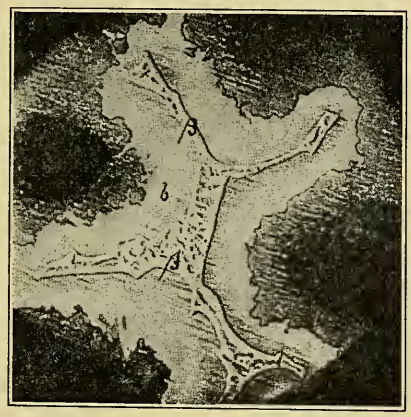
The tin oxidizing more readily, it is, as a rule, advisable to fuse the copper first, and then quickly introduce the tin. The heat should at the same time be increased so as to keep the alloy very thinly-fluid, the union of the two metals being accelerated by these means. The melted mass should at the same time be vigorously stirred with wooden rods, which not only accelerates the mixing but also counteracts the oxidation of the tin. Even with the use of all the above-mentioned precautions, the loss in fusing and casting always amounts to several per cent. of the weight of the metals used. Work where the loss is only one to two per cent. may be called excellent, as in many cases it amounts to ten per cent.

The loss of metal as well as the qualities of the castings are also considerably affected by the construction of the melting furnace. The more quickly the furnace can be heated to the temperature required for reducing the alloy to a fluid state the better it is for the purpose, for even with perfect protection against the action of oxygen, changes injurious to the homogeneity of the castings take place with long-continued fusion. If a bronze be intentionally kept in a fluid state for a long time, a white alloy very rich in tin is formed in it and is clearly perceptible in the castings. The alloy is no longer homogeneous, but actually consists of a mixture of several alloys differing very much in density, power

of resistance and strength, which seriously impairs the properties of the entire mixture. This separation or liquation of the alloy into two or more compounds occurs specially in mixtures most frequently used, *i. e.*, such as contain between 5 and 20 per cent. of tin; from alloys containing a lower or higher percentage of tin, homogeneous castings are more readily obtained.

Most bronzes have a strong tendency towards liquation and it is difficult to make thick castings from them without this liquation becoming perceptible. It is particularly plain to the eye with an alloy containing about 10 per cent. of

Fig. 17.



tin, the reddish fracture of which, if cooling has not been effected very rapidly, shows white spots, so-called tin-stains, due to an alloy richer in tin.

Although the liquation of bronzes has been the subject of numerous investigations, the opinions regarding the constitution of the bodies imbedded alongside each other in the solidified bronze have not yet been entirely elucidated.

Fig. 17 shows the ground surface, 365 times magnified, of a copper-tin alloy with 12 per cent. tin, after etching with cupro-ammonium chloride and annealing. *a* are mixed

crystals of copper and of a copper-tin combination. They form the constituent richest in copper of the structure and, as a rule, show a core somewhat richer in copper and a border somewhat richer in tin in consequence of the imperfect equilibrium between the separated crystals and the alloy still remaining fluid. *b* is a constituent of the structure richer in tin which is imbedded between the crystals *a*, and with a low content of tin appears as the eutectic alloy, while the latter, with the above-mentioned content of tin is formed by the included alloy *β* which is still richer in tin.

Since the liquation of an alloy rich in tin is promoted by slow cooling, the melted mass, which has a temperature of about 2552° F., must be cooled down as quickly as possible to 932° F., at which point, according to experience, the alloy richest in tin solidifies. This is, however, connected with many difficulties, especially in casting large pieces, such as cannon and bells, for which a perfect homogeneous metal is an absolute necessity.

The behavior of the solidified alloys towards the atmosphere varies according to their chemical composition, *i. e.*, they oxidize, on exposure to the air, in a shorter or longer time, acquiring thereby a color ranging from a beautiful green to black. This layer of oxide, which contributes much to the æsthetic effect produced by an article of bronze, is an important factor, especially to those occupied with casting statues, etc., and will be referred to later on.

Melting and Casting of Bronze.

The quantity of bronze to be prepared at one time varies according to the article to be cast, and may amount to a few ounces, or hundreds or thousands of pounds. Though the mode of preparing the bronze is the same in all cases, in the practice certain difficulties occur in casting small articles as well as large ones, which deserve attention.

For casting small articles a finished alloy of the desired proportions of metals is generally used, it being very diffi-

cult to hit the exact composition required in preparing small quantities of bronze. The fusion, in this case, is always effected in crucibles, special care being required to prevent as much as possible oxidation of the tin. The crucibles are placed in a wind-furnace and the surface of the bronze is kept carefully covered with pulverized coal, anthracite being best for the purpose on account of its great density.

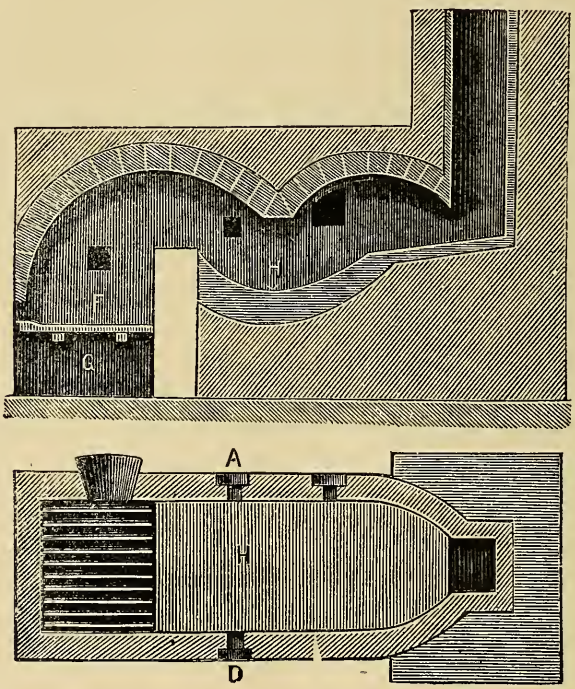
Attention has already been drawn to the fact that the temperature of the fused metal exerts a considerable influence upon the quality of the casting. Experience has shown that for small articles the bronze must not be heated too strongly, as otherwise the resulting casting is blown, and one blow-hole suffices to spoil it entirely. Articles to be subjected to hammering or stretching after casting must also not be cast too hot, in order to prevent them from acquiring a too coarsely crystalline structure.

Small castings cool off rapidly, but the effect of this, especially if not uniform, is to make portions of the mass considerably harder in some parts than in others, which renders mechanical manipulation difficult. It is therefore advisable to thoroughly heat the moulds before use, and to surround them with a bad conductor, for instance ashes, and also cover them with a layer of the same material after finishing the casting. Moulds of cast-iron or brass are generally used for small castings, which, in order to protect them, are coated with a mass consisting of lamp-black and oil of turpentine.

The preparation of large quantities of bronze as required for casting bells, cannon, or statues, is effected in reverberatory furnaces capable of holding up to 10,000 pounds of bronze or more. The copper is first melted, and, when fluid, any old bronze to be used is added. When all is converted into a uniform mass, the tin, previously heated as much as possible, is introduced in small portions. Immediately before the introduction of the tin, the fire must be

increased in order to compensate for the consequent reduction of the temperature, and to keep the metal in a thinly-fluid state. Figs. 18 and 19 show the arrangement of a reverberatory furnace especially adapted for melting not too large a quantity of bronze. *F* is the fire-box, and *G* the ash-pit. The metals to be melted are placed upon the

FIGS. 18 AND 19.

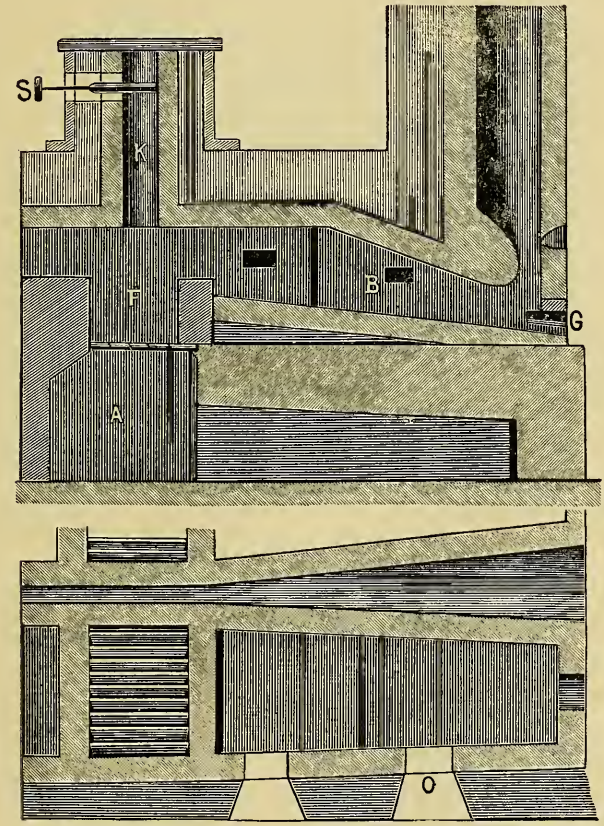


trough-shaped hearth *H*, while the aperture *D* serves for the introduction of the charge and for taking samples.

The finished bronze is run off through the aperture *D*. For large articles loam moulds are almost exclusively used, sand moulds being but seldom employed. While, as previously stated, it is advisable in casting small articles not to have the bronze too hot, for casting large objects it should

be very hot in order to render the production of uniform castings possible by keeping the mass in a fluid state for some time, and thus giving the gases evolved, as well as the oxides, a chance to rise to the surface.

FIGS. 20 AND 21.



Figs. 20 and 21 show the construction of a furnace especially adapted for melting a large quantity of bronze, which is to be as uniform as possible. The furnace, shown in Fig. 20 in section, and in Fig. 21 in ground-plan, has a capacity of about 16,200 pounds of bronze. Its total length

is 13 feet, and it is heated with wood. *F* is the fire-box and *A* the ash-pit, while the metals are melted in the space *B*, between *F* and *G*. *K* is the stoking-channel, which can be closed by the slide *S*. The aperture *O* serves for the introduction of the large pieces of metal, and the openings on the side for adding smaller pieces. *G* is the tap-hole closed during melting by a plug of clay.

The base of the hearth in these furnaces is, as will be seen from the illustrations, trapeziform, though there are other constructions in which it is elliptical or oval, or even circular, the latter form being frequently used, for instance, in casting statuary bronze. Figs. 22 and 23 show the construction of such a furnace, *S* being the hearth, *A* the fire-box, and *D* the foundry-pit in which the mould is placed. The aperture above *S* serves for the introduction of the metals, and that above *D*, which is closed during the melting with a plug of clay, for running off the fused metal.

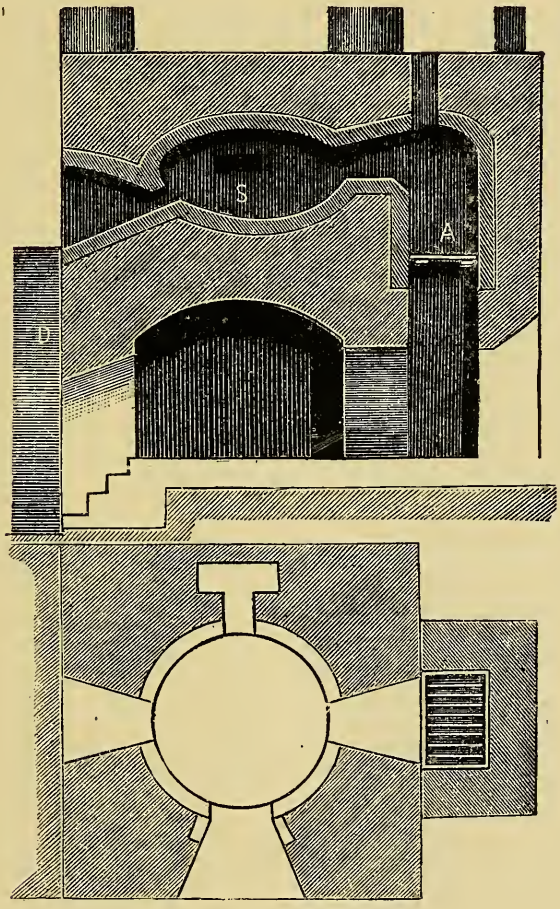
In a furnace of this kind up to 26,500 pounds of bronze can be melted for one casting. It is possible to construct furnaces of larger dimensions, but, on account of more uniform heating, it is recommended to use in this case several fire-places arranged on the circumference of the melting hearth.

The different kinds of bronze.—It will, of course, be readily understood that the composition of bronze must vary very much according to the purpose for which it is to be used. In practice a large number of alloys are distinguished, which, according to their application, are known by various names. To retain this division would lead to the enumeration of a large number of names, and we must therefore restrict ourselves to those most frequently used, such as gun-metal, statuary bronze, speculum metal, etc.

Before proceeding with the description of the preparation of the alloys serving for these purposes, it will be convenient to briefly refer to the bronzes of prehistoric times. It is well known that bronze was extensively used by the

ancients for coins, weapons, tools and ornaments. It might be supposed, at first sight, from the castings of the ancients, that they possessed some very expeditious and simple means of making their enormous and numerous productions

FIGS. 22 and 23.



in this department; but upon closer inspection this conclusion appears untenable, for many analyses of their alloys have demonstrated the fact that their bronzes were not a

constant composition of copper and tin, but contained frequently foreign metals, which cannot be considered as intentional additions, but only as accidental contaminations. Hence the success of a bronze of good composition was, no doubt, at that time, more a matter of accident than is possible with our present knowledge in regard to alloys, and the analyses of old bronzes can only give us hints about the behavior of the metals in the presence of substances to be considered as contaminations, without, however, contributing to the advancement of information in regard to the alloys. The researches made in modern times, especially as regards gun-metal, are so exhaustive in respect to the influence of the chemical composition of the alloy upon its physical qualities as to enable us to prepare alloys with any desired properties.

While the older bronzes, especially those of Greek origin, consisted almost only of copper and tin, in the older Roman coins considerable quantities of lead are frequently found, which must be considered as an intentional addition. Zinc seems to have first been intentionally added to bronze in the beginning of the present era. The exact composition of bronze has only been determined in modern times with the assistance of chemistry, the effect produced by the different elements upon the properties of the bronze, as well as the influence upon its physical qualities by rapid or slow cooling off, being now quite well understood. But that we have not yet arrived at a full knowledge of these properties is well seen from phenomena which in modern times have excited the interest of all technologists, it being only necessary to refer in this respect to phosphor-bronze and Uchatius's so-called steel-bronze.

Composition of some ancient bronzes:

	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.
Copper	86.38	80.91	88.70	92.07	68.42	81.76	83.65	88.06	95.0
Tin	1.94	7.55	2.58	1.04	0.94	10.90	15.99	11.76	4.5
Zinc	3.36	3.08	3.71	2.65	—	—	—	—	—
Lead	5.68	5.33	3.54	—	22.76	5.25	—	—	0.2
Antimony	1.61	0.44	0.10	—	0.67	—	—	—	—
Iron	0.67	1.34	1.07	3.64	4.69	0.15	trace	trace	0.3
Nickel	—	—	—	—	0.78	trace	0.63	trace	—
Cobalt	—	—	—	—	—	1.22	—	—	—
Sulphur	—	0.31	—	—	—	—	—	—	—
Arsenic	—	—	—	—	1.48	—	—	—	—
Phosphorus	—	—	—	—	—	—	0.05	0.03	—
Silica	0.10	0.16	0.09	0.04	—	—	—	—	—
Loss	0.26	0.79	0.21	0.56	0.26	0.72	—	0.15	—

Nos. 1 to 4 are examples from Japanese temples, according to Mauené; No. 5, an Egyptian figure, according to Flight, No. 6, from Cyprus at the time of Alexander the Great, according to Reyer; No. 7, an axe from Limburg with a thick coat of green patina, according to Reyer; No. 8, a chisel of a dark yellow color from Peschiera, according to Reyer; No. 9, old German chisel, according to Boussingault.

A Japanese bronze statue of Buddha weighing 450 tons is composed of copper 98.06, tin 1.68, mercury 0.21, gold 0.05.

Ordnance or Gun-Metal.

The use of bronze for casting cannon is said to have been known by the Arabs as early as the commencement of the twelfth century; in Germany the first bronze cannon were manufactured towards the end of the fourteenth century. Prior to that, after the invention of gunpowder, cannon of wrought-iron bars put together in the shape of a barrel and hooped with iron were used. While wrought-iron guns soon burst in consequence of the crystalline texture formed, cast-iron cannon of mottled iron are much more durable. Modern cannon of cast-steel are lighter, cheaper and generally more durable than bronze.

More money and labor have been spent on the study of gun-metal than on any other alloy, the governments of several of the larger countries having expended millions of dollars in experiments to find out the best alloys for the manufacture of ordnance. But that, nothwithstanding all this, a final result has not yet been arrived at is best proved by the many different opinions, some diametrically opposed to each other, in regard to the value of, for instance, the previously mentioned steel-bronze.

The properties demanded from a good gun-metal follow from the use of the cannon themselves. In firing a cannon an immense pressure, amounting to over 2000 atmospheres, is suddenly developed. To resist this pressure the material must possess great toughness, and cannon manufactured from bronze lacking this toughness burst generally with the trial-shots, for which especially large charges of powder are used. Gun-metal must further possess a high degree of hardness, as in firing the projectile strikes once or several times against the walls of the piece, it being impossible to give the same size mathematically accurate to the calibre of the piece and that of the projectile. If the bronze be not sufficiently hard, the interior of the piece loses after a few shots its cylindrical form, which is detrimental to the accuracy of the shot. Finally it must be considered that the gases evolved by the combustion of the powder attack the substance of the piece itself, and hence the composition of the bronze must be such that this chemical action is reduced to a minimum.

Briefly stated, good gun-metal must be very tough, capable of resistance, hard, and indifferent towards chemical influences, conditions which vary much from each other and are difficult to combine.

In order to obtain these properties all possible additions have been made to the actual bronze (consisting of tin and copper), and analyses of ordnance metal of different centuries and various countries plainly show the efforts made

to arrive at a correct composition of gun-metal by certain admixtures. In modern times the addition of foreign metals, with the exception of a small quantity of zinc or, in special cases, of phosphorus, seems to have been abandoned, the quality of the bronze being adapted to the desired purposes by suitable treatment in melting and casting. In older pieces a series of foreign metals is found, some of which as, for instance, nickel and cobalt, must be considered as accidental contaminations, since the preparation of these metals in a metallic form has only been known during more recent times. Iron, if present in a considerable quantity, is, no doubt, an intentional addition, and a content of bismuth can be explained by the fact that in connection with arsenic it was formerly used as a flux in the bronze mixture.

The content of tin in bronze which by experience gathered in the course of centuries has been found most suitable for casting ordnance, varies between 9 and 11 parts of it to 89 to 91 parts of copper. This composition corresponds quite closely to that used by the Greeks and other nations of ancient times for their weapons.

So many details essential for the success of the operation are connected with the melting and casting of alloys for the manufacture of pieces of ordnance, that a special volume would be required for a complete description of the various processes. We can, therefore, only give the merest outline, and must refer those especially interested to the treatises published on this subject. The principal requisite of an alloy answering all the demands of a good ordnance-bronze is the production of an entirely homogeneous casting, which it is endeavored to attain by solidifying the alloy under conditions allowing of its uniform cooling off. The moulds are always placed in a vertical position, and as the upper portions of the casting show frequently a different composition from the lower, this drawback is counteracted by using an excess of bronze, so that the finished casting has a long piece on top, the so-called "dead-head" or "sul-

lage-piece," which is later on sawed off and remelted with a new charge. This dead-head contains the greater portion of the alloys of dissimilar composition, and also the so-called "waste," consisting of oxidized metal.

Figs. 24 and 25 show a double furnace in use in the gun-

Fig. 24.

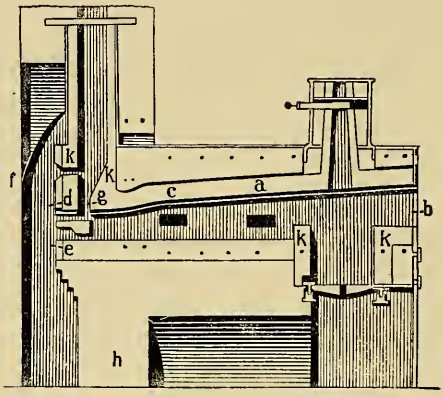
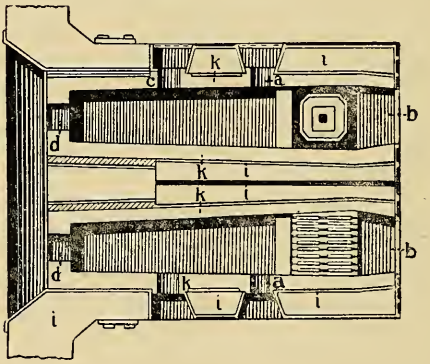


Fig. 25.

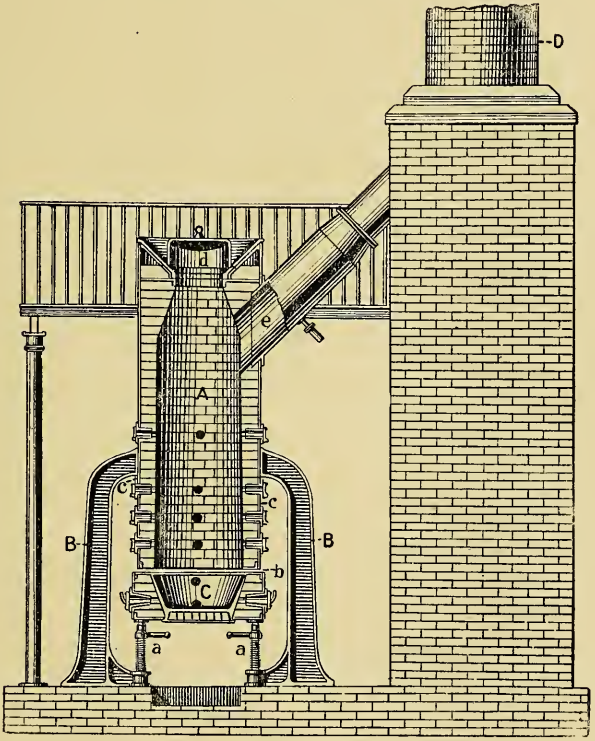


foundry at Spandau, in which 16,000 lbs. of gun-metal can be melted at one time. *b* is an opening through which larger masses may be brought upon the hearth, after which it is bricked up; *a* and *c* serve for the introduction of smaller masses of metal and for stirring; *e* is the tap-hole; *d* and *f*,

looking holes; *g*, flue. The portions indicated by *k* are constructed of refractory material. In this furnace the fusion of 16,000 lbs. of metal is effected in 3½ hours.

In several French foundries a shaft-furnace after the principal of Herbetz's steam-injector furnace is used, but the furnace works without steam, only the natural draught of

Fig. 26.



a sheet-iron chimney 82 feet high being used. The furnace shaft *A* (Fig. 26), 12½ feet high and 2¾ to 3 feet in diameter, contains the furnace and is supported in a frame by four cast-iron columes *B*, to which is also secured the movable hearth *C*, so that it can be raised or lowered at will by means of screws *a*, and the operator has it in his

power to regulate, according to the quality of the coke used, the width of the slit *b* between the edges of the shaft and the hearth which serves for the admission of air. *c*, *c* are looking holes; *d*, a Langen apparatus for closing the mouth of the shaft; *e*, a pipe conducting the gas into the chimney *D*. This furnace has the following advantages over a crucible furnace: Omission of crucible and blast, production of a beautiful fine-grained bronze on account of the evaporation of zinc present as contamination, consumption of only about 12 per cent. coke against 40 per cent. with crucible furnaces, more rapid fusion, and production of castings of any desired size with but one tapping.

In casting ordnance old cannon are frequently melted in, the practice in the opinion of many experts producing a favorable influence upon the homogeneousness of the resulting new material. The loss of tin by oxidation is also smaller, since tin once united with copper does not oxidize so readily as in the preparation of new alloys. But in order to obtain a homogeneous product great experience is required, and after the metals are melted, samples must be taken and examined as to their qualities, so that if the composition be not correct it can be improved by a suitable addition of copper or tin, or old bronze, as may be found necessary. A considerable time being, however, required for the newly added metals to form a homogeneous combination with the material already melted, great precaution is necessary to prevent the oxidation of the metals as much as possible. Strictly taken, it would be best to use gas only for melting bronze mixtures, since with the practice of this mode of firing not only the heat can be regulated at will, but a flame containing no free oxygen, and consequently capable of completely preventing the formation of waste, can be passed over the fusing mixture of metals.

The temperature at which ordnance-bronze is cast also exerts considerable influence upon its physical properties, one of about 2822° F. appearing to be the most suitable.

Cannon cast at this temperature are distinguished by great homogeneousness throughout the entire mass, and besides there need be no fear of the separation of the so-called tin-spots, one of which, if located in a place especially subjected to strong pressure in firing, suffices to render the entire piece useless in a short time.

Ordnance-bronze should be cooled off rapidly, this also decreasing the danger of the formation of tin-spots. Iron moulds are frequently used, but they must not be too cold, as otherwise the layers of bronze coming in immediate contact with the iron solidify so quickly as to prevent the mobility of the still fluid mass in the interior, which would produce an unequal tension of the molecules, in consequence of which the piece might burst with the first shot. In many ordnance-foundries sand moulds are used, there being a great diversity of opinion as to which method of casting is the most suitable. Cannon are now generally cast solid, and the cylindrical cavity is formed by boring out this solid mass. Some, however, consider it preferable to cast the piece over an iron mandrel, which is sometimes so arranged that water can circulate in it in order that the parts nearest to it may quickly solidify and become as hard as possible.

Steel-bronze.—The ordnance-bronze known under this name is prepared in the Austrian arsenals, the method of melting and subsequent treatment in casting being kept secret. It is only known that the bronze contains 8 per cent. of tin, and that the casting is effected in cold iron moulds. The peculiarity of the process of manufacturing ordnance from steel-bronze (also called Uchatius-bronze, after its inventor) consists in the piece after being finished to a certain extent being subjected to a peculiar mechanical treatment. The calibre of the piece is made smaller than it is finally to be, and is then gradually enlarged to the required diameter by steel-cylinders with conical points being forced through the cavity with the assistance of hydraulic presses. In consequence of this peculiar treatment the

cavity is, so to say, rolled or forged, the bronze acquiring the greatest power of resistance in those places which in firing are subjected to the greatest pressure.

The following table shows the composition of ordnance-bronze of various times and different countries:—

	Parts.					
	Copper.	Tin.	Lead.	Zinc.	Iron.	Brass.
United States	90	10	—	—	—	—
France (modern)	90.09	9.9	—	—	—	—
Prussia	90.90	9.1	—	—	—	—
England	89.30	10.7	—	—	—	—
France (1780)	100	—	—	—	—	61.0
Savoy (Turin, 1771)	100	12.0	—	—	—	6.0
Russia (1819)	88.61	10.7	—	—	0.69	—
Lucerne (Switzerland)	88.929	10.375	0.062	0.419	0.110	—
Cochin China	77.18	3.42	13.22	5.02	1.16	—
	93.19	5.43	—	—	1.38	—
China	71.16	—	—	27.36	1.40	—
Turkey (1464)	89.58	10.15	—	—	—	—
	95.20	4.71	—	—	—	—

Bell-Metal.

It was known in ancient times that certain alloys which, by reason of their composition, have to be classed with the bronzes, are distinguished by a specially pure tone on being struck. The ancient Hebrews, Babylonians and Egyptians made use of small hand-bells, and cymbals, especially at festivals and dances. The Romans had small bells at their house-doors and in the baths. In the temple of Proserpina at Athens bells announced the hour of the sacrifice; they sounded as a martial signal, and were secured to the triumphal car of the conqueror. The actual church bells were first introduced by Paulinus, Bishop of Nola in Campania.* In France bells were introduced about the middle of the sixth century, somewhat later in England, but in Germany

*Hence the word campanile.

only in the 11th century. The largest bells were cast in the middle ages, bell-founding flourishing especially from near the end of the 15th to the commencement of the 16th century. The weight of some of such large bells is as follows; Ivan Weliki at Moscow, Russia cast in 1653, 528,000 lbs.; this bell, as well as another weighing 316,800 lbs., at the same place, fell down. Two other bells at the same place weigh 176,000 and 156,200 lbs. respectively. A bell in Toulouse, France, weighs 60,500 lbs., one in the Stephan's tower, Vienna, 56,540 lbs., in St. Peter's church at Rome, 41,800 lbs., at Olmütz, 39,600 lbs., at Notre Dame, Paris, 35,640 lbs., at Milan, 33,000 lbs., and one, at Erfurt, cast in 1497, 30,250 lbs. Older bells in the cathedral at Cologne weigh 24,200 lbs. and 13,200 lbs. respectively, while the new Kaiser bell weighs 59,730 lbs.; it is 10 feet 8 inches high and 11 feet 4 inches wide.

Bell-metal must be hard to give a sound and not to suffer a change in form when the bell is subjected to the frequently repeated action of the clapper or tongue. It must therefore contain more tin than gun-metal. But notwithstanding the high content of tin it should not be more brittle than can be helped so as not to crack under these effects. For this reason the addition of other metals, besides copper and tin is excluded; in fact it is useless and in most cases injurious. Experience has shown that the best proportion of the two constituent metals is 20 to 23 parts tin to 77 to 80 parts copper. The quantities of incidental foreign constituents present, such as lead, iron, nickel, will of course be the greater, the more impurities are contained in the two metals used, and will therefore appear, as a rule, in greater abundance in old, than in new, bells. The content of lead amounts usually to 1 to 4 per cent. In some bells up to 1 per cent. of silver has been found, the opinion being formerly held that an addition of silver adds to the beauty of the sound, though from what has been previously said, it will be understood that such is not the case.

Bell-metal is brittle and cracks under the hammer, cold as well as heated. If it be repeatedly brought to a dark-red heat and quickly cooled by immersion in water, its brittleness is so far reduced that it can be hammered and stamped. The color of good bell-metal is a peculiar gray-white, differing materially from that of gun-metal and statuary bronze. The bell-founder judges the correct composition of the bell-metal by the appearance of the fracture; if the latter is too fine-grained the alloy is too rich in tin; if too coarse-grained it contains too little tin. The fracture is generally fine-grained and of a gray color. This is due to the brittleness of the whitish mixture rich in tin which more and more predominates and almost exclusively forms the surface of the fracture. The structure is distinguished from that of gun-metal by the predominance of denditric formations. It is scarcely possible to find upon the ground surfaces traces of net-work, aggregates of crystals resembling fir-tree branches appearing almost always, calling to mind by form and fineness chilled 10 per cent. bronze, but of a pale-yellow color and separated by an abundance of an intermediary substance of a grayish or whitish color.

Independent of the quality of the material used the tone of a bell depends materially on its size and form, the thickness of the walls and the proportion of height to diameter being also of importance for a beautiful and pure tone. The skill of the bell-founder lies not so much in finding the right composition of the alloy, this being thoroughly understood at the present time, as in giving the bell a shape corresponding to a certain tone, which is of special importance for chimes.

The melting and casting of bell-metal is not so difficult as that of ordnance-bronze, though great analogy exists between them. The copper is first melted down, and after heating the fused mass as much as possible, the tin is introduced and an intimate mixture promoted by vigorous stirring. Many bell-founders do not add all the tin at once,

but at first about two-thirds of it, and when this has formed a union with the copper, the other third.

It rarely happens that only new materials are used in preparing the bell-metal, old bells and ordnance-bronze being worked in large quantities. The composition of these should, however, be known so that the mean of the alloy will be such as to yield a bell of the required quality. For this purpose it is best to melt small portions of the respective metals together in the same proportions in which they are to be fused on a large scale. From the quality of these test-pieces it will then be seen whether a change in the composition of the alloy is necessary.

It is still more preferable to ascertain by a chemical analysis the centesimal composition of the metals, since the appearance of the fracture, color, and degree of brittleness give rise to error.

It has been frequently observed that bells repeatedly remelted acquire a disagreeable tone. The principal reason for this change is found in the solution of oxide in the alloy. This evil can be overcome by deoxidizing the mixture of metals, to which we will refer later on. While the composition of bell-metal for large bells is always within the above-mentioned limits, the material used for the manufacture of small tower-bells, table-bells, etc., varies very much, mixtures being often used which can actually not be classed as bell-metal, they being frequently only tin alloyed with a small quantity of copper and a little antimony.

The following table shows the composition of some bell-metals :—

	Parts.					
	Copper.	Tin.	Zinc.	Lead.	Silver.	Iron.
Normal composition....	80	20	—	—	—	
	78	22	—	—	—	—
Alarm bell at Rouen	76.1	22.3	1.6	—	1.6	
Alarm bell at Ziegenhain .	71.48	33.59	—	4.04	—	.12
Alarm bell at Darmstadt..	73.94	21.67	—	1.19	0.17	—
Alarm bell at Reichenhall (13th century).....	80	20	—	—		
Tam-tam	78.51	10.27	—	0.52	0.18	—
Bells of Japanese origin.	10	4	1.5	—	0.5	
	10	2.5	0.5	1.33	—	—
	10	3	1	2	½	—
	10	—	—	—	—	—

For *small clock-bells, table-bells, sleigh-bells,* etc., an alloy giving a clear and pure tone has to be used. Experience has shown that bell-metal with about 22 per cent. of tin gives the finest tone, and can therefore be suitably used for small bells. However, it is an object to use as cheap an alloy as possible for these purposes by a reduction of the content of the expensive copper. The following table will suffice to show the composition of such alloys:

	Parts.						
	Copper.	Tin.	Zinc.	Lead.	Silver.	Antimony.	Bismuth.
House-bells	80	20	—	—	—	—	—
House-bells, smaller.	75	25	—	—	—	—	—
Clock-bells, German .	73	24.3	2.7	—	—	—	—
Clock-bells, Swiss ...	74.5	25	—	0.5	—	—	—
Clock-bells, Paris....	72.0	26.56	—	—	1.44	—	—
Sleigh-bells	84.5	15.42	—	—	—	0.1	—
White table-bells	17	800	—	—	—	—	5
White table-bells	—	7	—	—	—	1	—

Chinese tam-tams or gongs are distinguished by a strong, far-reaching sound. The alloy of which they are made con-

sists in the mean of 80 parts copper and 20 parts tin. Genuine Chinese tam-tams are made, as shown by their appearance, from a thicker block of metal by forging with the hammer. However, bell-metal of the composition mentioned above is quite brittle at the ordinary temperature as well as at bright red heat, and its brittleness is but slightly decreased by tempering. The secret of the manufacture of tam-tams is found in the previously mentioned property of these alloys to suddenly become malleable at a perfectly dark red heat, but to rapidly lose this malleability at higher, as well as lower, temperatures.

Algiers metal (*metal d' Alger*).—This metal has a nearly pure white color and takes a beautiful polish. It can scarcely be classed with bell-metal, its composition having nothing in common with it. It is composed of copper 5 parts, tin 94.5, and antimony 0.5. The antimony is very likely added to give greater hardness.

Large bells are cast in loam moulds. The figures or designs with which the bell is to be ornamented are placed in the mould, the portions which have been left imperfect in casting being mended after the cast bell is cold. Small bells are generally cast in sand moulds, though recently iron moulds are frequently used.

Silver bell-metal.—This alloy suitable for small bells is distinguished by a beautiful silver-clear tone, and a nearly white color. It is composed of:

	Parts.		
	I.	II.	III.
Copper	40	41.5	41.6
Tin	60	58.5	58.4

Bronzes for Various Purposes.

As previously stated the properties of bronze may be varied within very wide limits according to the purpose for which it is to be used. A few of the most important bronzes used in the various branches of industry are here

given. To enter on a detailed description of all these alloys is scarcely practicable, since many manufacturers preparing bronzes for their special purposes use alloys which, as regards their centesimal composition (in respect to copper and tin), show considerable variations, and sometimes contain other metals as additions, which, according to the assertions of the manufacturers, impart to them exactly the properties desired.

According to the purposes for which the bronzes are to be used they may be designated, besides those already mentioned, as machine bronze (for bearings and pieces subject to severe friction), coin and medal bronze, and ormolu. The last alloy is chiefly used for small articles of art, and is by many classed among statuary bronze, but incorrectly so, because the latter, as will be explained later on, cannot be termed a bronze in the actual sense of the word. Besides the above-mentioned varieties of bronze, there remains to be mentioned the speculum metal, which was formerly much used for mirrors of optical instruments, but at the present its application is limited, these mirrors being now made by a cheaper process and at the same time of greater power.

Medal and coin-bronze.—A bronze suitable for these purposes must have a certain degree of ductility, be able to receive a true impression, and wear well. In many countries the baser coin is now made of a bronze-like alloy instead of pure copper as formerly, it being better calculated to resist the injuries it is likely to receive in circulation. The bronze used in casting medals contains a variable proportion of tin, ranging generally from 4 to 10 per cent., according to the depth of the impression. Bronzes containing about 8 per cent. of tin are distinguished by great hardness, but can be rendered sufficiently soft for stamping by heating to a red heat and tempering. This variety of bronze is chiefly used for medals which, besides being distinguished by artistic execution, are to have considerable durability. If the impression is to be quite deep, or if the medals are to be stamped several times, they must be repeatedly annealed.

An addition of a very small quantity of lead and zinc has a favorable effect upon the metal to be used for medals. It renders it softer, so that it can be worked with greater ease, and its color and fusibility are also improved.

The baser coin of many countries (France, Switzerland, Belgium, Italy, etc.) consists of a bronze of varying composition. The copper coin manufactured in France since 1852 consists, for instance, of copper 95 parts, tin 4, and zinc 1. This alloy has stood the test of time, coins stamped in 1852 still showing the impression in all its details, which is sufficient proof of its durability. Coin-bronze as made by the Greeks and Romans contained from 96 parts of copper and 4 of tin, to 98 parts of copper and 2 of tin. Chaudet has shown that the first of these alloys can be used for fine work, medals of this composition taking a very perfect polish while sufficiently hard to wear well.

Many medals, as is well known, do not show the color of bronze, but a pleasant brown, subsequently produced by oxidation. A bronze which, on account of its pale-red color, is especially adapted for medals with figures in high relief, consists of a mixture rich in copper. It is at the same time very flexible, so that the medals can be stamped without an expense of great power. This bronze consists of copper 97 parts, tin 2, and lead 1.

Medals whose size does not exceed a certain limit are at present stamped from sheet rolled out to the required thickness, and the blanks thus obtained stamped with the impression, this method being also used in making coins. For large medals with impressions in very high relief plates are prepared by casting, the model of the medal being used in order to obtain plates already somewhat raised or depressed on the respective places. As soon as the pieces cast in sand are solidified, they are thrown in cold water to give them the required degree of softness. After subjecting them to one or two pressures in the stamping-press, they must be again annealed in order to prevent cracking of the edges.

Ormolu (or moulu).—This alloy is much used for small statues, candlesticks, inkstands, etc., but serves also for purely artistic purposes. It also finds a very interesting application in the manufacture of articles coated with enamel. The enamel is placed in shallow cavities chiseled in the surface of the bronze and fused by heating the latter. Enamel of various colors can be used, each color being terminated by the edges of the cavities, and the articles after heating appear coated with the tightly-adhering enamel. Such work is termed *email cloisonné.* It became known in Europe through Chinese articles, but at present the European product by far surpasses the Chinese.

Below we give the composition of a few bronzes which can be classed with ormolu. They are much used in the manufacture of small articles of art, this industry being carried on to an enormous extent in Paris and Vienna.

Actual ormolu.—This bronze is distinguished by a pure golden-yellow color, and requires but little gold for gilding. It is much used for the finest bronze articles of luxury. It is composed of copper 58.3 parts, tin 16.7, zinc 25.3.

Bronze for small castings.—For articles to be prepared in large quantities, it is desirable to have a bronze which becomes very thinly-fluid in the heat and fills out the moulds. Cast-iron moulds are generally used, and the articles, as a rule, turning out very clean, can be at once brought into commerce after mending imperfect parts. A bronze of excellent quality for this purpose is composed of copper 94.12 parts, tin 5.88.

Gold bronze.—For many articles which are to present a beautiful appearance without being too expensive, it is scarcely practicable to provide them with a coating of genuine gold. An effort must, therefore, be made to impart to the alloy to be used a color resembling as closely as possible that of gold. A mixture possessing these properties in a high degree is composed of copper 90.5 parts, tin 6.5, and zinc 3.0. This alloy retains its beautiful gold color

on exposure to the air, but loses it rapidly if exposed to both air and water. Articles manufactured from it, if kept in a room, retain their color, and in the course of time act like all genuine bronzes, *i. e.*, they become covered with the characteristic green coating know as genuine patina, which is so highly valued on account of bringing out the beauty of the contours.

According to Maréchal and Saunier, a beautiful gold bronze is obtained if the tin be first purified by fusing with nitrate of soda, and the copper by fusing with saltpetre and potassium cyanide, and adding to the fused copper argol and potassium cyanide. The metals thus prepared are fused together with the addition of a mixture of sal ammoniac, potassium cyanide, phosphor-copper and Marseilles (castile) soap; before pouring out, a small quantity of sodium is added to make the alloy non-oxidizable.

Bronze to be gilded.—Every kind of bronze can be gilded, the gold adhering with great tenacity. An example of this is furnished in the equestrian statue of the Emperor Marcus Aurelius, standing in front of the capitol at Rome, which still show tracess of the gold with which it was at one time entirely coated. In making castings to be subsequently gilded, it is advisable to use an alloy which is distinguished by a beautiful gold color, such alloy, as previously mentioned, requiring the smallest possible quantity of gold. An alloy answering the purpose is composed of copper 58.3 parts, tin 16.7, zinc 25.3.

In many places, especially in Paris, much jewelry is made of bronze. The articles being generally turned out by stamping and finally gilded, the bronze used must have a certain degree of ductility and allow of being readily gilded. A mixture answering these demands, of which the greater portion of the Paris bronze jewelry is made, consists of copper 8 parts, tin 7.

Bronze for ship-sheathing.—A bronze containing 4.5 to 7 parts of tin to 100 parts of copper can be readily rolled

to sheets at a red heat, and in rolled plates with a content of 4.5 to 5.5 per cent. tin, resists the action of sea-water much longer than pure copper. With less than 3 per cent. tin its durability decreases essentially. It has been sought to replace a small portion of the tin by zinc or lead (0.5 to to 1.3 per cent.), it being claimed that the zinc makes the bronze more uniform. French bronze-sheet contains, according to Pufahl, copper, 91.57 per cent.; tin, 8.17; lead, 0.11; nickel, 0.08; and iron, 0.04.

Machine-bronze.—In this collective term are included a great number of alloys with very variable properties, and which have actually nothing in common except that they are used for certain parts of machinery. Many of these mixtures of metals—for some of them can scarcely be called bronzes—must be as hard as possible in order to resist wear; others must possess great strength so as not to yield under shocks or pressure, while still others must have the property of showing, even under a heavy load, but little frictional resistance when in contact with other metals.

Bronzes of ordinary composition differ but little as regards their properties from other cheaper metals and mixtures of metals, and, on account of their higher price, are but little used in the manufacture of parts of machinery, red brass being more frequently employed. The so-called white metal, which is distinguished by great hardness and comparative cheapness, finds however, much application for bearings. The white metals most frequently used in the manufacture of machines consist of alloys very rich in tin, containing besides this metal, antimony and a small quantity of copper.

Machine bronze.—On account of its considerable hardness and strength which can be readily regulated, bronze is used in the construction of machinery as a substitute for iron where rust or other influences would soon corrode the latter, or where two parts are subjected to friction and the unavoidable wear caused thereby is to be confined to

the part which can be most easily replaced, for instance, piston rings, bearings, etc. The most frequent application of bronze is for such parts which are in constant friction with iron parts.

In regard to the choice of a bronze as a substitute for the cheaper iron, it has of course to be taken into consideration that by its suitable composition less friction is to be produced than with iron upon iron. The most important point to be observed is, however, the fact that when two parts of the same material rub together, they also are, to approximately, the same extent subjected to wear, and have in a shorter or longer time to be replaced. If, on the other hand, one part is softer than the other, this alone is chiefly subjected to wear and requires to be replaced. Hence that portion of the two parts which can be replaced at the least expense is generally made of bronze, and the composition of the latter is sought to be so regulated that the object of protecting the more expensive part from wear is attained without, however, subjecting the bronze itself to more rapid wear than is absolutely necessary.

As such parts are cast, and an excessive degree of hardness would in most cases not even answer the purpose, larger or smaller quantities of zinc are generally added so that the composition of the bronze frequently corresponds with that of art bronzes. As with the latter a moderate addition of lead has sometimes been found suitable, casting and working with cutting tools being thereby facilitated, but the brittleness is, of course, increased. For machine parts readily subject to breaking, a large addition of lead is therefore injurious, and the value of antimony, which is also sometimes used, is questionable.

From what has been said it follows that the composition of machine bronze may vary very much and depends on the purpose for which it is to be used. Numerous formulas tested in practice have been recommended for the composition of machine bronze of which the following may serve as examples:

	Parts.			
	Copper.	Tin.	Zinc.	Lead.
Tough alloy for cocks, valves, etc.	88.0	12.0	3.0	—
Very tough alloy for eccentric rings	90.0	12.0	2.0	—
Another alloy for eccentric rings	84.0	14.0	2.0	—
Dense alloy for pump-bodies and valve-boxes.	88.0	10.0	2.0	—
Whistles for locomotives	80.0	18.0	2.0	—
Same with somewhat duller sound	81.0	17.0	2.0	—
Stuffing boxes, valve balls	86.2	10.2	3.6	—
Screw nuts for large threads	86.2	11.4	2.4	—
Piston rings	84.0	3.0	8.5	4.5
Piston rings	100.0	3.0	10.0	—
Distributing slide-valve	82.0	18.0	2.0	—
Gears in which teeth are cut	88.8	8.5	2.7	—
Gears in which teeth are cut	87.7	10.5	1.7	—
Gearing for spinning frames	90.0	10.0	—	—
Alloy for mathematical and physical apparatus but slightly subject to changes in temperature	82.0	13.0	5.0	—
Alloy for more delicate weights, balances and mathematical instruments	90.0	8.0	2.0	—
Propeller blades and boxes	57.0	14.0	29.0	—
Paddle-wheel pins	76.8	17.4	5.8	—
Cog-wheels	91.0	—	9.0	—

The following table shows the composition of various approved alloys for bearings.

	Parts.			
	Copper.	Tin.	Zinc.	Lead.
Ordinary bearings	84.5	13.3	2.2	—
Tough bearings	86.0	14.0	2.0	—
Bearing for French railroad cars	82.0	18.0	2.0	—
Bearing for locomotive axles	82.0	10.0	8.0	—
Bearing for locomotive axles*	73.5	9.5	9.5	7.5
Stephenson's bearing for locomotive axles	79.0	8.0	5.0	8.0
Bearings for very hard axles	82.0	16.0	2.0	—
Bearings for moderately hard axles	70.0	22.0	8.0	—
Bearing of the Penna. Railroad Co.	77.0	8.0	—	15.0

*This alloy contains in addition to the other metals 0.5 per cent. of iron, and has stood the test for several years.

In the tables below the mixtures employed by a large engineering firm, using scrap and new metal are given. *

	Parts.				
	Copper.	Spelter.	Lead.	Tin.	Old metal.
Bearing brasses	38	1	—	7	54
Eccentric pumps	38	1	—	4	57
Pumps	38	4	—	3	55
Cocks and glands	38	6	1.5	1.5	53
Sluice cock-way	38	9	—	—	53

	Parts.			
	Copper.	Tin.	Spelter.	Old metal.
Bearing brasses	56	8.5	2.5	45
Eccentric pumps	28	6.5	7.5	70
Kingston valve	112	14	—	7
Paddle-wheel pins	56	12.5	3.5	40
Propeller blades and boxes	16	4	8	84

	Parts.			
	Ingot copper.	Block tin.	Zinc.	Old brass.
Heavy bearings	16	2.5	0.75	—
Heavy bearings	16	3	—	13
Main bearings	16	2 to 3	—	32
Propeller shaft liner	56	6	—	50

Bronze for articles exposed to shocks and very great friction.—Copper, 83 parts; tin, 15; zinc, 1.5; lead, 0.5.

Bronze for valve-balls and other constituent parts to

*Hiorns. "Mixed Metals."

which other parts are to be soldered with hard solder.—Copper, 87 parts; tin, 12; antimony, 1. This alloy is flexible, and of a red, granular fracture.

Bronze resisting the action of the air.—For this purpose Bath recommends a mixture of 576 parts of copper, 48 of brass, and 59 of tin.

A bronze for the same purpose can, however, also be obtained by mixing together 26 parts of copper and 2 of tin.

A beautiful bronze, which can be used for most purposes as a substitute for brass, and also as hard solder for copper, is obtained, according to Eisler, by mixing together 16 parts of copper and 1 of tin. It is golden-yellow, can be hammered and stretched, is harder and more plastic than brass and copper, nearly as hard as wrought-iron, and runs more easily and thinner than brass.

By remelting the quality of the bronzes is impaired, they becoming more thickly-fluid and their brittleness increases. This deterioration is due to the absorption of oxygen by the liquid alloy, the oxygen being chemically fixed. In addition to cuprous oxide, stannic acid and copper stannate have to be taken into account. This deterioration of the bronzes cannot be removed by melting under a cover of charcoal as has been shown by exhaustive experiments. Charcoal, to be sure, has a reducing effect, but only when in direct contact with the oxides. Since the charcoal, however, does not pass into solution with the alloy, the crystals of cuprous oxide, and especially the stannic acid formed, and present in the alloy in the shape of threads and thin skins, do not rise at all or at least very sluggishly, and the charcoal cannot produce a reducing effect or only a very limited one. These drawbacks can only be removed by refining the old material, and old copper to be rendered suitable for the preparation of bronze must also be refined. This is best effected by poling with green wood as sappy as possible, for instance, green birch poles. During the poling samples should at short intervals be taken and examined as

to structure and toughness, the latter by hammering and bending tests. Poling too long continued makes the copper brittle. The slags are withdrawn from the surface of the metal-bath, and towards the end of the poling operation the melted copper is covered with charcoal.

Old bronzes and old copper may also be sufficiently deoxidized by the addition of a small quantity of phosphor-copper.

A few words may here be added, regarding defective bronze castings. Such castings can be but seldom, or not at all, recognized from the outside, it only becoming apparent in further working the casting that it is honeycombed with blisters and pores, and unfit for use. This is unfortunately found out only when the work has quite far advanced, and the time and labor spent is thus lost. The formation of blisters and pores is due to the development of gases in consequence of decompositions which take place in the liquid metal, it being, in fact, nearly always dissolved oxides which by acting upon other dissolved constituents, form new liquid oxygen combinations and, in this manner, cause development of gas. The formation of oxides frequently takes place during melting by the absorption of oxygen from the air or the fire gases, the latter being especially the case when the time of melting is for any reason prolonged or melting is effected in a reverberatory furnace. By the addition of deoxidizing agents it is sought to destroy the oxides present and which may be formed, and, in fact, bronze should not be cast without treating, for the sake of precaution, the contents of the crucible with such a deoxidizing agent. For this purpose small additions of phosphorus in the form of phosphor-copper are very suitable, also small quantities of manganese-copper and magnesia-copper. Quite porous green moulding sand should be used, and the mould be provided with good vent-holes for the passage of the gas.

Speculum Metal.

Alloys, composed of two-thirds copper and one-third tin, take a beautiful polish and can be used as mirrors. At the present time such alloys are only used in the construction of mirrors for optical instruments, especially for large telescopes, though they are being gradually displaced by glass mirrors.

Good speculum metal should be perfectly white, without a tinge of yellow, having a fine-grained fracture, and be sound and uniform, and sufficiently tough to bear the grinding and polishing without danger of disintegration. A composition answering all purposes must contain at least 65 to 66 per cent. of copper. The specula made by Mudge contained from 32 parts of copper and 16 of tin to 32 of copper and 14.5 of tin. A little tin is lost in fusion. It has been frequently attempted to increase the hardness of speculum metal by additions of arsenic, antimony, and nickel. With the exception of nickel these additions have, however, an injurious effect, the specula readily losing their high lustre, this being especially the case with a larger quantity of arsenic. According to Bischoff a mirror composed of 66.3 per cent. copper, 32.1 tin and 1.6 arsenic, which possessed a white color and excellent lustre, after some time suddenly tarnished and became coated with a green patina. Sollitt claims that an addition of arsenic during fusion prevents oxidation of the tin.

It would seem that the actual speculum-metal is a combination of the formula Cu_4Sn, and has the following centesimal composition :—

Copper	66.6
Tin	33.4
	100.0

According to David Ross the best proportions are: Copper 126.4, tin 58.9, *i. e.*, atomic proportions. He adds the molten tin to the fused copper at the lowest safe tem-

perature, stirring carefully, and securing a uniform alloy by remelting.

The so-called tin-spots which sometimes separate when ordnance-bronze is incorrectly treated form an alloy similar in composition to speculum metal; it has, however, not a pure white color, such as is found in those containing 31.5 of tin. By increasing the content of copper, the color shades gradually into yellow, and with a large content of tin, into blue. It is risky to increase the content of tin too much, as besides the change in color the alloy becomes brittle and cannot be further worked. The following table shows the composition of some alloys used for speculum-metal. It may, however, be remarked that the standard alloy is undoubtedly the best for the purpose:—

	Parts.				
	Copper.	Tin.	Zinc.	Arsenic.	Other metals.
Standard alloy	68.21	31.79	—	—	
Otto's	68.5	31.5	—	—	
Richardson's	65.3	30	0.7	2	2 silver.
Little's	65	30.8	2.3	1.9	
Sollit's	64.6	31.3	—	—	4.1 nickel.
Chinese speculum metal	80.83	—	—	—	8.5 antimony.
Old Roman	63.9	19.05	—	—	17.29 lead.

Other compositions: Copper 32, brass 4, tin 16½, arsenic 1¼. Copper 32, tin 15 to 16, arsenic 2. Copper 32, tin 15½, nickel 2.

According to Boedicker, the mirror of the celebrated Ross telescope, which has a diameter of 6 feet and weighs 11,000 lbs., is composed of copper 70.24, tin 29.11, zinc 0.38, iron 0.10, lead 0.01, and nickel 0.01.

For the manufacture of concave mirrors an alloy of copper 18, tin 18, zinc 18, nickel 36, and iron 10, has been recommended.

In conclusion the composition of a few recent and old bronze mirrors may be given:

Telescope mirror at Birr Castle, Ireland, weighing 5000 kilogrammes (11,000 lbs.): Copper 70.24 per cent., tin 29.11 per cent., and in addition, small quantities of iron, nickel and zinc.

A beautiful mirror in the Polytechnikum, Brunswick, Germany: Copper 65.1 per cent., tin 32.8 per cent.

Roman metal mirror found in Mayence: Copper 63.4 per cent., tin 19.0 per cent., lead 17.3 per cent.

Old Egyptian metal mirror. Copper 85 per cent., tin 14 per cent., iron 1 per cent.

Chinese metal mirrors, probably the so-called *magic mirrors,* * contained, besides copper, antimony and lead, for instance, copper 80.8 per cent., antimony 8.4 per cent., lead 9.7 per cent., and therefore cannot be designated as bronzes in the actual sense of the word.

Phosphor-Bronze.

In the actual sense of the word, phosphor-bronze cannot be considered an alloy containing a fixed quantity of copper, but it is rather a bronze subjected to a peculiar treatment with the use of certain phosphor-combinations.

It has been previously mentioned that bronze frequently contains a considerable quantity of cuprous oxide in solution, which is formed by direct oxidation of the copper during fusion, and that the admixture of this oxide impairs to a great extent the strength of the alloy. If now the melted bronze be treated with a substance exerting a powerful reducing action, as, for instance, phosphorus, a complete

*Figures or inscriptions cast upon the back of such mirrors appear more or less plainly in the light reflected from the front. Thicker places—in this case the figures upon the back—turn out porous in casting and being more firmly pressed together by the subsequent grinding and polishing, reflect the light differently from the thinner parts. Such mirrors can also be made from other copper-alloys.

reduction of the cuprous oxide takes place, the pure bronze acquiring thereby a surprisingly high degree of strength and power of resistance. If exactly the quantity of phosphorus required for the complete reduction of the oxide has been used, no phosphorus will be found in the alloy, but the latter must nevertheless be called phosphor-bronze. Hence it will be readily seen that phosphor-bronze is not a special alloy, but that every kind of bronze can be converted into it. With the use of combinations of phosphorus, phosphor-bronze is therefore deoxidized bronze.

Phosphor-bronze has long been known to chemists, but its valuable qualities as a material to be used in construction were first made known by Montefiori-Levi and Künzel, who discovered the alloy in 1871. Besides reducing any oxides dissolved in the alloy, the phosphorus exerts another very material influence upon its properties. The ordinary bronzes consist of mixtures in which the copper actually forms the only crystallized constituent, the tin crystallizing with great difficulty, and the alloy in consequence of this dissimilar condition of the two metals is not so solid as it would be if both constituents were crystallized. The presence of phosphorus is useful in giving the tin a crystalline character, which enables it to alloy itself more completely and firmly with the copper, the result being a more homogeneous mixture.

If so large a content of phosphorus be added that it can be identified in the finished phosphor-bronze, the latter must be considered as an alloy of crystallized phosphor-tin with copper. By increasing the content of phosphorus still more, a portion of the copper also combines with the phosphorus, and the bronze then contains, besides copper and tin, combinations of crystallized copper phosphide with phosphide of tin. The strength and toughness of the bronze do not suffer by a greater addition of phosphorus, but its hardness is considerably increased, so that many phosphor-bronzes are equal in this respect to the best steel, and some even surpass it in general properties.

Perhaps about the best method of making phosphor-bronze is to line the crucible with a mixture of 18 parts bone ash, 14 parts sand and 4 parts charcoal; the whole ground up with gum water and the inner surface of the crucible spread with it. Granulated copper is then introduced, covered with a layer of the mixture and subjected to fusion.

At a temperature sufficient to melt the copper, the silica decomposes the bone ash [$Ca_3(PO_4)_2$], the base of which (calcium) is removed, thus liberating the phosphorus which reacts on the cuprous oxide in the fused copper, deoxidizing and purifying it. The products of the reaction rise to the surface and form a slag which can be tapped off.

Another, and perhaps the most general, method of making phosphor-bronze is the addition of phosphor-copper or of phosphor-tin, both of these phosphor-metals being sometimes used at the same time. They must be especially prepared, the best processes being briefly as follows:—

Phosphor-copper is prepared by heating a mixture of 4 parts of super-phosphate of lime, 2 parts of granulated copper, and 1 part of fine-pulverized coal in a crucible at not too high a temperature. The melted phosphor-copper, which contains 14 per cent. of phosphorus, separates on the bottom of the crucible.

According to another method phosphor-copper is prepared by adding phosphorus to copper-sulphide solution and boiling, adding sulphur as the sulphide is precipitated. The precipitate is carefully dried, melted, and cast into ingots. When of good quality and in proper condition, it is quite black.

Phosphor-tin is prepared as follows: Place a bar of zinc in an aqueous solution of chloride of tin, collect the sponge-like tin separated and bring it moist into a crucible, upon the bottom of which sticks of phosphorus have been placed. Press the tin tightly into the crucible and expose it to a gentle heat. Continue the heating until flames of burning

phosphorus are no longer observed on the crucible. After the operation is finished, a coarsely crystalline mass of a tin-white color, consisting of pure phosphor-tin, is found upon the bottom of the crucible.

Phosphor-tin may also be made by heating 3 parts of anhydrous phosphoric acid with 1 part carbon and 6 parts tin. The resulting alloy has a silver-white crystalline appearance, and dissolves in hydrochloric acid with the evolution of sulphuretted hydrogen. According to Pelletier, this alloy appears to possess the composition of Sn_3P_2; it melts at 698° F.

Phosphor-bronze is prepared by melting the alloy to be converted into it in the usual manner, and adding small pieces of phosphor-copper or phosphor-tin. For 220 lbs. of bronze 21 to 24 ozs. of phosphor-copper with 15 per cent. phosphorus are used.

Whiting prepares *phosphor-bronze wire* by immersing the alloy in a solution of 0.125 to 5 per cent. phosphorus in ether, carbon disulphide or olive oil, 5 to 10 per cent. sulphuric acid and 85 to 95 per cent. water, and drawing into wire.

The properties of correctly prepared phosphor-bronze are as follows: Its melting point is nearly the same as that of ordinary bronze. In cooling it shows, however, the phenomenom of passing directly from the liquid into the solid state without first becoming thickly-fluid. In a melted state it retains a perfectly bright surface, while that of ordinary bronze is always covered with a thin film of oxide.

If phosphor-bronze be subjected to continued melting no loss of tin takes place, but the content of phosphorus decreases slightly.

The chief properties of phosphor-bronze are its extraordinary toughness and strength. In a cold state it can be rolled, stretched and hammered.

According to Kirkaldy phosphor-bronze produced the following results by physical tests:—

	Elastic Limits. Pounds per Square Inch.	Tensile Strength. Pounds per Square Inch.	Elongation. Per Cent.
Cast	23.800	52.625	8.40
Cast	24.700	46.100	1.50
Cast	16.100	44.448	33.40

Drawn Metal (*Phosphor Bronze*).

Tensile Strength.		Twists in 5 Inches.		Elongation. Per cent.
Wire as Drawn. Pounds per Square Inch.	Annealed. Pounds per Square Inch.	Wire as Drawn.	Annealed.	
102,759	49,350	6.7	89	37.5
120,957	47,787	22.3	52	34.1
120,950	53,381	13.0	124	42.4
139,141	54,111	17.3	53	44.9
159,515	58,853	13.3	66	46.6
151,119	64,569	15.8	60	42.8

Besides, as a bearing metal phosphor-bronze is useful for a large number of purposes, such as pump-cylinders, hydraulic presses, piston rings, eccentric rings, etc.; also for propeller blades, bells, wire, screws, gunpowder machinery, tools, etc. Blast furnaces are sometimes provided with phosphor-bronze tuyeres, which are said to give most satisfactory results.

The content of phosphorus varies according to the purpose for which the bronze is to be used, an alloy with 8 to 9 per cent. tin containing, as a rule, not over a few tenths per cent. Pufahl found in a bronze of 91 per cent. copper and 8.5 tin not over 0.1 per cent. phosphorus, the remainder being nickel, lead and iron. According to Priwoznick the content of phosphorus ranges from 0.17 to 0.76 per cent. but, according to Künkel. it may rise to 2½ per cent., according to the purpose for which the bronze is intended. Ledebur found in a phosphor-bronze with 0.004 per cent. phosphorus 0.038 per cent. oxygen.

According to Thurston five sorts of phosphor-bronze are considered to answer all requirements.

0. Ordinary phosphor-bronze of 2 per cent. of phosphorus.
1. Good phosphor-bronze of 2½ per cent. of phosphorus.

These two numbers are in all cases superior to ordinary bronze and steel.

2. Superior phosphor-bronze of 3 per cent. of phosphorus.
3. Extra phosphor-bronze of 3½ per cent. of phosphorus.
4. Maximum phosphor-bronze of 4 per cent. of phosphorus.

These three, according to Delalot, are superior to any other bronzes. Above No. 4 phosphor-bronze is useless, below No. 0 it is inferior to common bronze and steel. Nos. 3 and 4 are comparatively unoxidizable.

In the following a few analyses of different kinds of phosphor-bronzes are given:

Copper	90.34	90.86	94.71
Tin	8.90	8.56	4.39
Phosphorus	0.76	0.196	0.053

	I.	II.	III.	IV.	V.	VI.	VII.	VIII.
Copper	85.55	—	—	77.85	72.50	73.50	74.50	83.50
Tin	9.85	4 to 15	4 to 15	11.00	8.00	6.00	11.00	8.00
Zinc	3.77	—	8 to 20	7.65	17.00	19.00	11.00	3.00
Lead	0.62	4 to 15	4 to 15	—	—	—	—	—
Iron	trace	—	—	—	—	—	—	—
Phosphorus	0.05	0.5 to 3	0.25 to 2	—	—	—	—	-

No. I. for axle bearings; Nos. II. and III. for softer and harder axle bearings; Nos. IV. to VIII. for railroad purposes, viz.: No. IV. for distributing slide valves for locomotives; Nos. V. and VI. for axle bearings for cars; No. VII. for connecting rods; No. VIII. for piston rods for hydraulic presses. The alloys IV. to VIII. are richer in zinc than ordinary bronze, and hence more homogeneous.

On account of its toughness, density, elasticity and strength, phosphor-bronze may in many cases serve as a substitute for wrought iron and steel, especially in the construction of articles of complicated form, which require much labor, as well as in the manufacture of wire, for instance, for non-rusting mine ropes and telegraph wire. It is also suitable for ship-sheathing, for torpedoes instead of welded steel, for cartridge shells, etc. According to Pufahl, Höper's phosphor-bronze wire is composed of copper, 95.59 per cent.; tin, 3.60; lead, 0.50; iron, 0.07; nickel, 0.24; and phosphorus, 0.37; an alloy from Iserlohn was found to contain copper, 92.12; tin, 4; zinc, 3.69; lead, a trace; iron, 0.05; nickel, 0.16; and phosphorus, 0.06. The absolute strength of Höper's cable rope is 212,500 lbs. per square inch, and sheet, for instance for flap valves, is said to surpass even caoutchouc as regards elasticity.

Bender, Stöckman and Stölzel give the following analyses of Höper's phosphor-bronze:

Copper	90.34	90.86	94.70	93.68	94.11
Tin	8.90	8.56	4.39	5.83	5.15
Zinc	—	—	—	0.34	0.28
Phosphorus	0.76	0.196	0.053	0.17	0.21

No. II. is especially suitable for blast-furnace tuyeres; and No. III for bearings.

Phosphor-lead bronzes have also been prepared, Lavroff's bronze containing copper 70 to 90 per cent., tin 4 to 13, lead 5.5 to 16, and phosphorus 0.5 to 1. Kühne's phosphor-lead bronze contains, according to Pufahl, copper 78.01 per cent., tin 10.63, lead 10.45, iron 0.09, nickel 0.26, and phosphorus 0.57.

Phosphor-aluminium bronze.—Thos. Shaw, of Newark, N. J.,* patents a phosphor-aluminium bronze, making the following claims: First, an alloy of copper, aluminium and phosphorus, containing 0.33 to 5 per cent. of aluminium,

*U. S. patent 303,236, Aug., 1884.

0.05 to 1 per cent. of phosphorus, and the remainder copper. Second, its manufacture by melting a bath of copper, adding to it aluminium in the proportions stated, the bath being covered with a layer of palm oil to prevent ozidation, and then adding a small proportion of aluminium.

Silicon Bronze.

Copper and silicon, with or without tin, may be alloyed to form silicon bronze. Weiller's alloy is made by the introduction of sodium to reduce silica in the crucible. The inventor recommends the following proportions: Fluosilicate of potash 450 parts by weight, glass in powder 600, chloride of sodium 250, carbonate of soda 75, carbonate of lime 60, and dried chloride of calcium 500. The mixture of these substances is heated in a plumbago retort to a temperature a little below the point when they begin to react on one another, and it is then placed in a copper or bronze bath, when the combination of silicon takes place.

Silicon acts upon copper in almost exactly the same manner that phosphorus does, except that it appears to be a more natural alloy, and a flux or reducing agent to the cuprous oxide that is produced when copper is in a melted condition, and it is thereby more active in clarifying, refining, hardening, and strengthening copper and its alloys. In this respect it is more vigorous and pronounced than phosphorus.

Silicon bronze possesses great strength and tenacity, high electric conductivity and resistance to corrosion. It is well adapted for telegraph and telephone wires. Early specimens of silicon-bronze wire for telegraph purposes had a conductivity of 97 per cent., and a tensile strength of about 28½ tons to the square inch; that for telephone purposes had a conductivity of 32 per cent. and a tensile strength of 47½ tons to the square inch.

Later on a new type of telegraph wire was developed; which possessed less conductivity than the former, but had

considerably greater tensile strength which allowed of the wire being more tightly stretched so that the poles could be placed at a greater distance apart. This wire has a conductivity of 80 per cent., and a tensile strength from 35 to 37 tons to the square inch. At the same time the character of the telephone wire was also changed, raising its conductivity to 42 per cent., and its tensile strength to 52 tons. These wires have been largely used for telephone lines at Prague, Trieste, Lemberg, and other European cities. The line at Trieste, in particular, has stood the test of violent storms completely, which is due to the small diameter of the conductor. A similar experience has been had at Rheims, where, in one case, a line having a span of more than a thousand feet was exposed to the action of the wind blowing directly across it.

Its power of resisting snow has been equally well established. Thus, on an Austrian railway the engineer at the head of the telegraph department personally examined the wires during a violent storm of damp snow, followed by a sharp frost, at a point where the line crosses hilly ground at a height of about 2,000 feet above the sea. The wires were well covered with snow and sagged considerably more than usual. In several instances by shaking the wire the snow was detached, when the conductors immediately assumed their normal deflections after the snow had melted. The Austrian railway company above mentioned has numerous lines on which the distance between posts varies from 328 to 720 feet across flat country; in hilly districts the distant ranges from 160 to 500 feet.

The "Italian General Telephone Co." has employed silicon-bronze wires with spans as great as one thousand feet. In Vienna telephone posts are frequently placed at the same distance apart, and carry as many as 78 wires.

Silicon-bronze telegraph wire (I) and silicon-bronze telephone wire (II) of Weiller's patent silicon-bronze contain, according to Hampe:

	I.	II.
Copper	99.94	97.12
Tin	0.03	1.14
Iron	trace	trace
Zinc	—	1.62
Silicon	0.02	0.05

The following compositions of silicon-bronze may be recommended:

	I.	II.
Copper	97.12	97.37
Tin	1.14	1.32
Zinc	1.10	1.27
Silicon	0.05	0.07

Strength of the above alloys, 600 lbs. per 0.001 square inch, extension 46 per cent., contraction 86 per cent. Cast pins 3 inches thick could be readily reduced by rolling to 1 inch thick.

Bronze for telephone lines.—E. Van der Ven* has instituted a careful investigation on wires of phosphor-bronze and silicon-bronze. The wires experimented with contained, according to chemical analysis made for him by M. Van Eyndhoven, in the case of the phosphor-bronze: Copper 95.5 per cent., phosphorus 2.6 per cent., with small quantities of tin, manganese, and silicic acid; in the silicon bronze: Copper 92.2 per cent., silicon 0.91 per cent., together with small quantities of tin, manganese and antimony.

The practical results of Dr. Van der Ven's researches are that phosphor-bronze has about 30 per cent. of the conducting power of copper, silicon-bronze about 70, while steel as used in wires has only about 10.5 per cent. Comparing their tenacity, as also very carefully determined by him, with that of steel, he finds that a wire of the latter material, of 2 millimeters diameter, with quadruple security and the conventional sag of 0.7 millimeter, can have a

*Musée Teyler, and Electrotech. Zeitsch., 1883.

stretch from pole to pole of 130 meters, while the stretch, under the same conditions of a wire 1 millimeter in diameter would for phosphor-bronze be 106 meters for silicon-bronze 91 meters. These alloys, with a diameter of 1.18, and of 0.77 millimeters respectively, have the same electrical resistance as the steel wire of 2 millimeters resistance. The relatively short stretch which in general increases the expense of construction and maintenance, is less costly in cities, where at short distances the roofs of buildings offer points of suspension for telephone wires. It is thus self-evident that the bronze wires are preferable to those of steel, whose resistance demands a much larger section; the more, since the net-work of lines suspended in the air cannot be counted among the ornaments of a large city. To this result may be added the statements made by M. Bede, at the Paris Electrical Congress, concerning the practicability of the use of phosphor-bronze wire. A phosphor-bronze wire of 0.8 millimeter (costing, too, the same as steel of 0.2 mm.) would, on account of its high elasticity, coil up, before it has fallen 4 meters from its original position, so rapidly that on breaking it would ordinarily not strike the ground, and hence would be less dangerous. On account of non-oxidation there is no loss of diameter.

Manganese bronze.—By the addition of manganese to the melted bronze, the same effect may be produced as by a limited quantity of phosphorus, the dissolved oxides being decomposed and manganous oxide separated.

In 1840, Gersdorff prepared cupro-manganese with manganese 1 part and copper 4 parts, and shortly afterwards Schrötter prepared it with 10 to 19 per cent. manganese by reducing a mixture of copper scales, pyrolusite and coal. In 1876, Parson obtained ferriferous cupro-manganese by melting ferro-manganese in a crucible and adding copper and, in 1878, Biermann produced cupro-manganese free from iron which contained 74.50 per cent. copper, 25 per cent. manganese, and 0.50 per cent. carbon. By its content of

manganese the alloy exerts, in a manner similar to that of phosphorus and silicon, a reducing effect upon the oxides absorbed by melting bronze, etc., manganous oxide being formed and separated, so that with a moderate addition (3 to 6 per cent. of the weight of the charge) only small quantities of manganese remain in the alloy, the strength of the latter being thereby increased. For reducing purposes a quantity of manganese about four times as large as the cheaper phosphorus is required. By a larger addition of manganese, so that more of it remains in the alloy, hardness and strength are increased, but brittleness less rapidly than by phosphorus.

Cupro-manganese may be prepared as follows: Bring into a graphite crucible of about 35 to 60 lbs. capacity a mixture of powdered manganese ore, coal dust and granulated copper, give a cover of fluor-spar, common salt and charcoal dust, expose the crucible to a white heat for several hours, and pour out the liquid alloy; the result will be a hard, tough, strong, whitish-gray product. By reason of incomplete reduction up to 10 per cent. of manganese is scorified, and the furnace as well as the crucible is strongly attacked.

To partly overcome these drawbacks, Allen melts in a reverberatory furnace with regenerative firing a mixture of cupric oxide, coal and manganic oxide, the latter obtained from the manganiferous liquid resulting as a by-product in the manufacture of chlorine, or prepared from manganous carbonate, the result being a malleable, ductile alloy containing 5 to 30 per cent. manganese, which is claimed to possess greater toughness than copper.

Valenciennes reduces pyrolusite in a magnesia crucible lined with pyrolusite, and melts the resulting metallic manganese with copper to alloys containing 3 to 8 per cent. manganese. Such alloys are soft and ductile, while with 12 to 15 per cent. manganese they acquire a gray color, are hard and brittle, and more readily fusible. By an addition

of zinc, alloys resembling German silver are obtained, which are ductile, cold as well as hot, while German silver has always to be worked hot.

Parkes heats ½ to 100 parts by weight of manganese ore with 50 parts of cuprous oxide and 75 parts anthracite in a covered crucible to a red heat six to ten hours. After cooling a friable mass is obtained, in which the alloy is found in small globules. The latter are separated by sifting, and washed.

With a smaller quantity of manganese, for instance, 4 per cent., cupro-manganese has a copper-red color, with a larger content (10 to 15 per cent.) a yellowish-gray color, and with a still larger content, for instance, up to 30 per cent., a gray color. According to Weiller, an alloy with 8 per cent. manganese can be readily rolled, but with 12 to 15 per cent. becomes very brittle. An alloy of copper 75 and manganese 25 resists corrosion better than copper. According to Pufahl, two varieties of cupro-manganese contained:

Copper.	Manganese.	Iron.	Nickel.	Lead.	Silicon.
68.39	29.24	1.29	0.19	0.06	0.07
56.29	40.86	1.50	0.10	trace	1.08

Cupro-manganese, generally with 10 to 30 per cent. manganese, serves as an addition to copper or metallic alloys to impart to them, by the withdrawal of oxygen, greater density and strength, and, with a larger content of manganese, greater hardness. If in the oxidation of the manganese trimanganic tetroxide is formed, 1 part oxygen requires 2.585 parts manganese, but only 0.646 parts phosphorus.

For the preparation of manganese-bronze, add to ordinary bronze melted in a crucible under a cover of charcoal to which potash or soda may be added, small pieces of cupro-manganese previously warmed, heat, stir several times with a rod of retort-graphite, or of burnt wood, and pour out

the alloy; or first melt the copper and old metal together with the cupro-manganese in a crucible under a cover of charcoal dust, then add the required tin, and stir thoroughly with the graphite rod.

The quantity of cupro-manganese to be added depends on its content of manganese, but if the object is only the withdrawal of oxygen 3 to 4 per cent. suffices. In this case only small quantities of manganese remain in the alloy. However, an excess of a content of manganese impairs the qualities of the alloy less than one of phosphorus, it rather acting similarly to tin, *i. e.*, increases the hardness and strength, but the brittleness less rapidly than phosphorus. Manganese-bronzes in the actual meaning of the word have been made from manganese and copper, or manganese, copper and tin, or manganese, copper, tin, and zinc with a content of up to 10 per cent. of manganese. Such alloys are intended for various purposes, especially for the manufacture of machine parts, as a substitute for ordinary bronze free from manganese. However they have found but a limited application, and by no means that of phosphor-bronze. The reason for this may be found in the fact that if the object is simply the withdrawal of oxygen, four times more manganese is required than phosphorus and thus the process, notwithstanding the lower price of manganese, becomes more expensive. Furthermore, manganese does not effect the strength of the alloy in the same degree as tin and while a content of the latter decreases the melting point of the alloy, one of manganese increases it and hence bronze containing tin can be more easily cast than manganese bronze.

According to Cowles, an addition of up to 5 per cent. aluminium increases the strength and elasticity of manganese bronze, makes it more easy to cast, and gives it a silver-white appearance. An alloy of manganese 18, copper 67.5, aluminium 1.2, silicon 5 and zinc 13 is said to be superior to German silver for the manufacture of rheostats,

and its electrical resistance is claimed to be 41 times greater than that of copper. By remelting, even under a cover of coal, manganese is oxidized.

Tough, malleable manganese bronze of almost a brass-yellow color contained, according to Gintl, copper 75 to 76, manganese 16 to 17, zinc 5 to 6; or copper 15, manganese 4, zinc 1.

The statements regarding the properties of manganese-bronze vary considerably. It is interesting to find in this connection that, about the year 1868, Messrs. Montefiore-Levi and Künzel made a number of experiments with copper and manganese alloys, and from their results concluded such alloys to be useless. They obtained great tensile strength and toughness with some of the compositions, but their ready oxidation at high temperatures made the qualities of the castings uncertain and impracticable.

More recent experiments are, however, more favorable. According to Biermann, the most advisable addition to bronze is ⅔ per cent. manganese = 2⅔ per cent. cupro-manganese with 25 per cent. manganese; in many cases an addition of 0.5 to 2 per cent. cupro-manganese suffices, the alloys then containing only a few hundredths per cent. of manganese. While good qualities of ordinary bronze broke under a pressure of 39.6 lbs. per square millimeter, bronze with ⅔ per cent. manganese stood a pressure of 62.15 lbs. with an elongation of 20½ per cent. On account of its great homogeneity such manganese bronze possesses great resisting power against wear by friction; bearings of bronze with ½ to ⅔ per cent. manganese being much more durable than other bearing metals without manganese. An alloy of copper 80, cupro-manganese 7 to 9, tin 6, and zinc 5 has proved especially suitable for bearing metal.

Art Bronzes.

This term is applied to bronzes which serve for objects of art, such as statuary, vases and various ornaments. Such

bronze should be capable of being cast, and of being readily worked with chasing tools and gravers. It should resist the influence of the weather and at the same time, by reason of its hardness resist mechanical wear. It should have a beautiful color which, to be sure, soon changes under atmospheric influences, *i. e.*, becomes darker and partially passes into green, but notwithstanding this change is pleasing to the eye, and never acquires an unsightly appearance like, for instance, that of rusted iron or oxidized zinc.

For casting statues the actual bronze may be advantageously used, and many antique statues are composed of this material. But in modern times a mixture of metals is used, which besides copper and tin—the constituents of actual bronze—contains a quantity of zinc, the alloy thus formed being actually an intermediary between genuine bronze and brass. The reason for the use of such mixtures must partially be sought in their cheapness as compared with genuine bronze, and partially in the purpose for which the metal is to be used. A statuary bronze which thoroughly answers the purpose must become thinly fluid in fusing, fill the moulds out sharply, allow of being readily worked with the file, and must acquire a beautiful green color—the patina—on exposure to the air for a short time.

But the actual bronze, even if highly heated, does not become sufficiently fluid to accurately fill out the moulds, and has the further disadvantage of yielding homogeneous castings with difficulty. Brass by itself is also too thickly-fluid, and lacks the requisite hardness to allow the fine mending of those parts which have been left imperfect in casting.

Alloys containing zinc and tin, besides copper, can, however, be so prepared that they become very thinly-fluid, and yield fine castings which can be readily worked with the file and chisel. The most suitable proportions seem to be a content of zinc of from 10 to 18 per cent. and one of tin of from 2 to 4 per cent. In regard to hardness, statuary

bronze is a mean between genuine bronze and brass, it being harder and tougher than the latter, but surpassed in these properties by the former.

Statuary bronze being chiefly used for artistic purposes, its color is of great importance. By small variations in the content of tin and zinc which must, however, be always kept between the indicated limits, the color may be shaded from orange-yellow to pale yellow, With an excessive content of tin the alloy becomes brittle and difficult to chisel, and by increasing the content of zinc the warm tone of color is lost, and the bronze does not acquire, on exposure to the air, a fine patina.

This pale-green patina, the beautiful development of which is especially noticeable upon ancient, particularly Greek, bronzes, consists essentially of oxides and basic carbonates of the constituents of the bronze and is formed in the course of time by the chemical action of moisture and the oxygen and carbonic acid of the air. The beautiful patina should possess a lustrous tone of color and a smooth surface. Articles coated with it should even after centuries preserve their contours in all their fineness and sharpness as produced by casting and subsequent working, as well as their metallic luster.

Such a patina may be noticed on copper which has been used for roofing and for chased work as, for instance, the Victory group upon the Brandenburg gate at Berlin, as well as on numerous bronzes with, and without, the addition of zinc and lead. On the other hand, copper-zinc alloys without tin, usually turn black when exposed to the air, especially when the content of zinc is a considerable one (brass), and become coated with a rough, dull layer of oxide, the formation of which very soon impairs the sharpness of the contours. Many bronzes show a similar behavior. Hence it is evident that the composition of bronze articles erected in the open air exerts an influence upon the permanency of their beauty and many investigations have

been made to answer the question of what is the most suitable composition of bronzes for the formation of a beautiful patina. It has been found, at least generally speaking, that bronzes rich in zinc and poor in tin are in this respect inferior to those poorer in zinc, and that incidental admixtures are also not without influence upon the formation of patina, a content of arsenic especially contributing towards the bronze turning black. A small content of lead such as is generally found in European bronzes, does not seem to have an injurious effect. Moreover the location of the bronze article exerts an influence upon the formation of the patina. In a smoky atmosphere or in one containing sulphuretted hydrogen, even the best bronzes acquire a black, instead of a, green coating, which consists partially of cupric sulphide and partially of mechanically deposited soot.* On the other hand, even bronzes rich in zinc acquire a green patina if located in pure air and exposed to atmospheric influences. Finally, it cannot be doubted that the processes of moulding and casting are not without influence upon the subsequent formation of patina. Porous castings with rough surfaces will more readily accumulate dust and soot and be less inclined to the formation of a beautiful patina than dense castings with smooth surfaces.

Though the alloys best adapted for statues are definitely known at the present time, it happens sometimes that many large castings do not exhibit the right qualities. Their color is either defective, or they do not acquire a beautiful patina, or are difficult to chisel. These evils may be due either to the use of impure metals or to the treatment of the alloy in melting. On account of the large content of zinc there is a considerable loss in melting, amounting even

*In the black coating of the monument of the Elector at Berlin, which was formerly covered with a beautiful patina but has now turned black, Weber found 5.79 per cent. of sulphur and particles of soot. In the black coating of two Nuremberg statues, Kämmerer found 4.1 to 6.8 per cent. sulphur and large quantities of sand and soot.

with the most careful work to at least 3 per cent., and sometimes reaching 10 per cent., and it is evident that in consequence of this loss the alloy will show an entirely different composition from what it should have according to the quantity of metal used in its preparation.

The color of the alloys, as mentioned above, quickly changes by variations in their compositions. The following table gives a series of alloys of different colors suitable for statuary bronze :—

Copper.	Zinc.	Tin.	Color.
84.42	11.28	4.30	red yellow.
84.00	11.00	5.00	orange-red.
83.05	13.03	3.92	"
83.00	12.00	5.00	"
81.05	15.32	3.63	orange yellow.
81.00	15.00	4.00	"
78.09	18.47	3.44	"
73.58	23.27	3.15	"
73.00	23.00	4.00	pale orange.
70.36	26.88	2.76	pale yellow.
70 00	27.00	3.00	"
65.95	31.56	2.49	"

According to d'Arcet the best bronze for statues consists of copper, 78.5 parts; zinc, 17.2; tin, 2.9; and lead, 1.4; or, of copper, 164 parts; zinc, 36; tin, 6; and lead, 3.

In the following table will be found the composition of a few celebrated statues :—

	Copper.	Zinc.	Tin.	Lead.	Iron.	Nickel.	Antimony.
Equestrian statue of Louis XIV, cast 1699, by Keller	91.40	5.35	1.70	1.37	—	—	—
Statue of Henry IV, Paris	89.62	4.10	5 70	0.48	—	—	—
Equestrian statue of Louis XV	82 45	10.30	4.10	3 15	—	—	—
Minerva statue, Paris	83	14	2	1	—	—	—
Statue of Napoleon, Paris	75	20	2	2	—	—	—
Old Vendome column, Paris, from captured cannon	89.2	0.5	10.2	0.1	—	—	—
Alloys of Stiglmayr, Munich, for instance, statue of Bavaria	91.5	5.5	1.7	1.3	—	—	—
Statue of Lessing, Brunswick.	84.2	11.5	3.55	0.75	—	—	—
Statues of Melanchthon, Wittenberg, and of Frederick William IV, Cologne, by Gladenbeck	89.55	7.46	2.99	—	—	—	—
Statue of Count Brandenburg, of Thaer, and of the lion fighter in front of the Museum, Berlin, by Gladenbeck	88.88	9.72	1.40	—	—	—	—
Statue of Blücher, Berlin	90.1	5.3	4.6	—	—	—	—
Statue of Frederick the Great, Berlin	88.3	9.5	1.4	0.7	—	—	—
Shepherd, Potsdam Palace	88.66	1.28	9.70	0.77	—	—	—
Bacchus, " "	89.54	1.63	7.50	1.21	0.18	—	—
Germanicus, Potsdam	89.78	2.35	6.16	1.33	—	0.27	—
Statue of the Great Elector, Berlin, erected 1703	89.09	1.64	5.82	2.62	0.13	0.11	0.60
Statue of Frederick William, Berlin	87.44	8.89	3.20	0.65	—	—	—
Horse-tamer, Berlin	84.55	15.63	0.14	0.16	—	—	—
Statue of the Elector John William, Düsseldorf	71.74	25.58	2.37	0,91	—	—	—
Statue of Albrecht Dürer, Nürnberg	88.6	0.1	5.2	4.5	—	—	—

Chinese bronzes.—Some bronzes exhibited at the Paris Exhibition attracted special attention, not only on account of their artistic beauty, but also on account of the unusually deep bronze color, which, in many specimens, presented a beautiful dead-black appearance. The color, which was doubtless intended to contrast with the silver of the filigree work was proved to belong to the substance proper of the bronze, and not to have been artificially produced by an application upon its surface. Analyses of the different specimens of the bronze gave the following results:—

	Parts.		
	I.	II.	III.
Tin	4.36	5.52	7.27
Copper	82.72	72.09	72.32
Lead	9.9	20.31	14.59
Iron	0.55	1.73	0.28
Zinc	1.86	0.67	6.00
Arsenic	—	trace	trace

These alloys contain a much larger proportion of lead than is found in ordinary bronze; and it is noticeable that the quantity of lead increases precisely with the intensity of the bronze color, proving, as before stated, that the latter is due to the special composition of the bronze.

Some of the specimens contain a considerable proportion of zinc, but the presence of this metal, instead of improving the appearance, seemed rather to counter-balance the effect of the lead.

In imitation of the Chinese bronze some alloys were made of the following composition.—

	I.	II.
Tin	5.5 parts.	5.0 parts.
Copper	72.5 "	83.0 "
Lead	20.0 "	10.0 "
Iron	1.5 "	— "
Zinc	0.5 "	2.0 "

No. I. produced an alloy exceedingly difficult to work, and, without giving any superior results as regards color, furnished castings which were extremely brittle.

No. II., on the contrary, gave an alloy exactly resembling the Chinese bronze. Its fracture and polish were identical, and when heated in a muffle it quickly assumed the peculiar dead-black appearance so greatly admired in the Chinese specimens.

Hitherto it has been found difficult, if not impossible, to obtain this depth of color with bronzes of modern art, since the surface scales off when heated under similar conditions as No. II.

Japanese bronzes.—An analysis of Japanese bronzes made by M. E, J. Maumené gave the following results:—

Copper	86.38	80.91	88.70	92.07
Tin	1.94	7.55	2.58	1.04
Antimony	1.61	0.44	0.10	1.04
Lead	5.68	5.33	3.54	1.04
Zinc	3.36	3.08	3.71	2.65
Iron	0.67	1.43	1.07	3.64
Manganese	0.67	trace	1.07	3.64
Silicic acid	0.10	0.16	0.09	0.04
Sulphur	0.10	0.31	0.09	0.04
Waste	0.26	0.79	0.21	0.56

All these alloys show a granulated texture, are blistered in the interior, and sound on the exterior surface. In the presence of an abundance of antimony their color is sensibly violet, and red in the presence of iron. The specimens were cast thin, from 0.195 to 0.468 inch, and the mould was well filled.

Old Peruvian bronze.—An old chisel, weighing about 7 ounces, found in Quito, and which had evidently been used for working trachyte,* showed according to Boussingault the following composition: Copper 95.0 parts, tin 4.5, lead 0.2, iron 0.3, silver, traces.

A chisel brought by Humboldt to Europe from a silver mine worked by the Incas consists of copper 94 per cent., tin 6 per cent. Charlon ascribes the hardness of the tools used by the Peruvians in mining, which consisted of copper 94 per cent. and tin 6 per cent., to the presence of a small quantity of silicon.

A Turkish bronze basin examined by Fleck was composed of copper 78.54 parts, tin 20.27, lead 0.54, iron 0.19.

An antique bronze weapon in the form of a chisel, which was found near Bremen, was composed of copper 85.412 parts, tin 6.846, iron 0.346.

*A nearly compact, feldspathic, volcanic rock, breaking with a rough surface, and often containing crystals of glassy feldspar, with sometimes hornblende and mica.

Melting and casting art-bronze.—On account of the oxidability of the bronze used for statues and other objects of art, certain precautions have to be observed in melting in order to reduce the loss to a minimum. Crucibles are used for melting small quantities, and reverberatory furnaces for melting larger quantities for statues, etc. In melting in the crucible all the constituents of the bronze are, as a rule, introduced at one time, while in melting in a reverberatory furnace any old metal to be used together with the

Fig. 27.

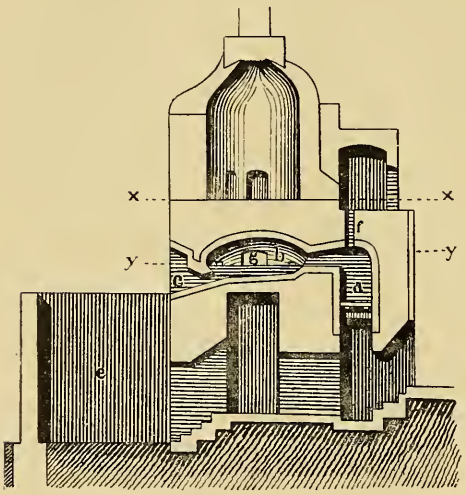
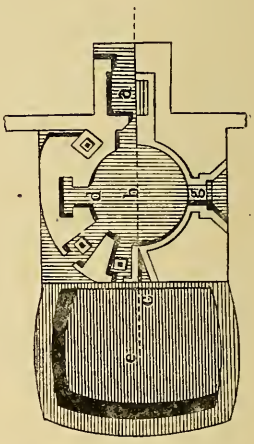


Fig. 28.



copper is first melted; the previously heated zinc is then added, and finally the tin. The loss or waste varies according to the composition of the alloy, the period of melting, and the arrangement of the furnace, and amounts with the use of a reverberatory furnace to between 5 and 10 per cent.; less with the use of a crucible.

Figs. 27 and 28 exhibit a furnace used in the Royal Foundry in Munich. The charge is 27,500 lbs. Fig. 27 shows the section in the direction of x x, and Fig. 28 in the direction of y y. *A* is the grate, *b* the hearth, *c* the tap

hole, *d* are air channels in the external wall for carrying off the products of combustion, *e* is the foundry-pit, *f* stoke channel, *g* charging holes.

The operation is commenced by heating the furnace to a red heat, and then quickly introducing the copper. The latter being melted, it is covered with a layer of coal, and the previously-heated zinc added. Immediately after the introduction of the latter the tin is added, and the fused mass frequently stirred with wooden poles in order to prevent, by the products of distillation evolved from the wood, the oxidation of the metals, and to promote the homogeneity of the alloy.

Before using the metal for casting, many founders draw it in a very thinly-fluid state into a pan or kettle standing in front of the tap-hole, and allow it to stand for some time in order to separate on the surface any oxide still contained in the alloy, which otherwise would injure the purity of the casting. After the layer of oxide is removed, the clay-plug closing the discharge-aperture in the bottom of the pan is removed, and the metal allowed to run into the mould placed in the pit directly in front of the furnace.

Loam-moulds can only be used for large castings, and it being impossible to previously heat them, the fused metal is introduced from below and gradually rises to the top. When it runs from the apertures in the top of the mould and from the vent-holes, the mould has been successfully filled.

The following table * is a list of about 140 different alloys of copper and tin, giving some of their mechanical and physical properties :—

*Prepared originally for United States Board; Committee on Metallic Alloys. Report, Vol. I, 1879, p. 390.

Properties of the Alloys of Copper and Tin.—Comparison of several authorities.

Atomic formula.	Composition of original mixture.		Composition by analysis.		Specific gravity.	Color.	Fracture.	Tenacity, pounds per square inch.	Order of ductility (Mallet).	Relative ductility (Thurston).	Hardness (Mallet, and Calvert and Johnson).	Order of malleability (Mallet).	Order of fusibility (Mallet).	Conductivity for heat, silver = 100.	Conductivity for electricity silver = 100.	Authority.	Remarks.
	Cu.	Sn.	Cu.	Sn.													
—	100	0	—	—	8.791*a* 8.874*b*	Copper-red	Fibrous	27,800	—	30.8	—	—	—	—	—	U. S. B.	*a*. Specific gravity of bar. *b*. Specific gravity of turnings from ingot.
—	100.00	0.00	—	—	8.667	Tile-red	Earthy	55,104	1	—	10	2	16	—	—	M.	
—	100.00	0.00	—	—	8.921	—	—	—	—	—	—	—	—	—	93.16	Ma.	
—	100.00	0.00	—	—	—	—	—	—	—	—	301	—	—	81.1	—	C. J.	
—	100.00	0.00	—	—	8.794	—	—	—	—	—	—	—	—	—	—	Cr.	
—	100.00	0.00	—	—	8.921	—	—	—	—	—	—	—	—	—	—	Mar.	Cast copper.
—	100.00	0.00	—	—	8.952	—	—	—	—	—	—	—	—	—	—	Mar.	Sheet copper.
—	100.00	0.00	—	—	—	—	—	—	—	—	—	—	—	73.6	79.3	We.	
—	100.00	0.00	—	—	8.672	—	—	24,252	—	—	—	—	—	—	—	Na.	Mean of 9 samples.
—	98.59	1.41	—	—	—	—	—	—	—	100.1	—	—	—	—	62.46	Ma.	
$SnCu_{96}$	98.10	1.90	97.89	1.90	8.564	Red	Vesicular	—	—	—	—	—	—	—	—	U. S. B.	Defective bar.
—	98.04	1.96	—	—	—	—	—	—	—	—	—	—	—	—	—	Bo.	Can be forged like copper.
—	98.00	2.00	—	—	—	—	—	—	—	—	—	—	—	—	—	La.	Ramrods for guns.
—	97.50	2. 0	—	—	8.511	Red	Vesicular	—	—	—	—	—	—	—	—	U. S. B.	Defective bar.
—	96.97	3.03	—	—	—	—	—	—	—	—	—	—	—	—	—	W.	Resists action of hydrochloric acid.
$SnCu_{48}$	96.27	3.73	96.06	3.76	8.649	Reddish-yellow	Vesicular	32,000	—	70.3	—	—	—	—	—	U. S. B.	
—	96.00	4.00	—	—	8.947	—	—	—	—	—	—	—	—	—	—	Ri.	Annealed & compressed.
—	95.00	5.00	—	—	—	Golden yellow	—	—	—	—	—	—	—	—	—	W.	Hard, malleable.
—	94.10	5.90	—	—	—	—	—	—	—	—	—	—	—	—	—	Bo.	Pieces of machines.
—	94.00	6.00	—	—	8.939	—	—	—	—	—	—	—	—	—	—	Ri.	Specific gravity after repeated tempering.
—	93.98	6.02	—	—	—	—	—	—	—	—	—	—	—	—	19.68	Ma.	
$SnCu_{25}$	93.17	6.83	—	—	8.820	—	—	—	—	—	602.8	—	—	—	—	C. J.	
$SnCu_{24}$	92.80	7..0	—	—	8.694	Reddish-yellow	Vesicular	28,510	—	21.9	—	—	—	—	—	U. S. B.	
—	92.50	7.50	—	—	8.684	Reddish-yellow	Vesicular	27,900	—	43.2	—	—	—	—	—	U. S. B.	
—	92.00	8.00	—	—	—	—	—	—	—	—	—	—	—	—	—	Bo.	Bronze for medals.
—	91.75	8.25	—	—	—	—	—	—	—	—	—	—	—	—	—	W.	Shows separation of metals when examined with a lens.
—	91.74	8.26	—	—	—	—	—	—	—	—	—	—	—	—	—	Bo.	English ordnance.
—	91.70	8.30	—	—	—	—	—	—	—	—	—	—	—	—	—	Bo.	Ordnance metal.

Properties of the Alloys of Copper and Tin.—Continued

Atomic formula.	Composition of original mixture.		Composition by analysis.		Specific gravity.	Color.	Fracture.	Tenacity, pounds per square inch.	Order of ductility (Mallet).	Relative ductility (Thurston).	Hardness (Mallet and Calvert and Johnson).	Order of malleability (Mallet).	Order of fusibility (Mallet).	Conductivity for heat, silver = 100.	Conductivity for electricity, silver = 100.	Authority.	Remarks.
	Cu.	Sn.	Cu.	Sn.													
—	91.66	8.33	—	—	—	—	—	—	—	—	—	—	—	—	—	Bo.	8-pounder guns.
$SnCu_{20}$	91.59	8.51	—	—	8.793	—	—	—	—	—	639 8	—	—	—	—	C. J.	
—	91.30	8.70	—	—	—	—	—	—	—	—	—	—	—	—	—	Bo.	Toothed wheels.
—	90.91	9.09	—	—	—	—	—	32,193	—	—	—	—	—	—	—	Mus.	Prussian ordnance.
—	90.90	9.10	—	—	—	—	—	—	—	—	—	—	—	—	—	Bo.	Ordnance metal.
—	90.73	9.27	—	—	—	—	—	—	—	—	—	—	—	—	—	Bo.	French ordnance.
—	90.10	9.90	—	—	—	—	—	—	—	—	—	—	—	—	—	Bo.	
—	90.00	10.00	90.27	9.58	8.669	Grayish-yellow	Earthy	26,860	—	18.0	—	—	—	—	—	U. S. B.	Compressed ordnance bronze. [sion.
—	90.00	10.00	—	—	8.875	—	—	—	—	—	—	—	—	—	—	De.	After repeated compres-
—	90.00	10.00	—	—	8.935	—	—	—	—	—	—	—	—	—	—	Ri.	Railroad car bearings.
—	90.00	10.00	—	—	—	—	—	—	—	—	—	—	—	—	—	Bo.	Ordnance metal.
—	89.30	10.70	—	—	—	—	—	—	—	—	—	—	—	—	—	Bo.	Small bar cast in iron mould.
—	89.29	10.71	—	—	8.953	—	—	37,688	—	—	—	—	—	—	—	Wa.	Small bar cast in clay mould.
—	89.29	10.71	—	—	8.313	—	—	25,783	—	—	—	—	—	—	—	Wa.	Mean of 12 gun-heads.
—	89.29	10.71	—	—	8.353	—	—	26,011	—	—	—	—	—	—	—	Wa.	Ordnance metal.
—	89.23	10.77	—	—	—	—	—	—	—	—	—	—	—	—	—	Bo.	
$SnCu_{15}$	89.00	11.00	—	—	8.84	—	—	—	—	—	—	—	—	—	—	Ri.	
$SnCu_{15}$	88.97	11.03	—	—	8.825	—	—	—	—	—	772.92	—	—	—	—	C. J.	Mean of 83 gun-heads.
—	88.89	11.11	—	—	8.523	—	—	—	—	—	—	—	—	—	—	Wa.	
—	88.39	11.61	—	—	—	—	—	—	—	—	—	—	—	—	12.10	Ma.	Gun metal.
—	88.00	12.00	—	—	—	—	—	—	—	—	—	—	—	—	—	La.	
—	87.65	12.35	—	—	—	—	—	—	—	—	—	—	—	—	10.15	Ma.	
—	87.50	12.50	—	—	8.648	Grayish-yellow	Earthy	31,100	—	7.3	—	—	—	—	—	U. S. B.	
—	86.80	12.40	—	—	—	—	—	—	—	—	—	—	—	—	—	W.	
$SnCu_{12}$	86.57	13.43	87.15	12.73	8.681*a* 8.943*b*	Mottled-white and yellow	Finely vesicular	29,430	—	13.09	—	—	—	—	—	U. S. B.	*a*. Specific gravity of bar. *b*. Specific gravity of fine turnings. [(Riche).
—	86.21	13.79	—	—	8.87	—	—	—	—	—	—	—	—	—	—	W.	Densest of all alloys (?)
—	86.00	14.00	—	—	—	—	—	—	—	—	—	—	—	—	—	W.	Axle-tree bed, Seraing
—	85.71	14.29	—	—	—	—	—	44,071	—	—	—	—	—	—	—	Mus.	[locomotive.
—	85.09	14.91	—	—	—	—	—	—	—	—	—	—	—	—	8.82	Ma.	

Properties of the Alloys of Copper and Tin.—Continued.

Atomic formula.	Composition of original mixture.		Composition by analysis.		Specific gravity.	Color.	Fracture.	Tenacity, pounds per square inch.	Order of ductility (Mallet).	Relative ductility (Thurston).	Hardness (Mallet, and Calvert and Johnson).	Order of malleability (Mallet).	Order of fusibility (Mallet).	Conductivity for heat, silver=100.	Conductivity for electricity, silver=1.0.	Authority.	Remarks.
	Cu.	Sn.	Cu.	Sn.													
$SnCu_{10}$	84.33	15.67	—	—	8.87	—	—	—	—	—	—	—	—	—	—	Ri.	
—	84.30	15.68	—	—	8.832	—	—	—	—	—	916 66	—	—	—	—	C. J.	
—	84 29	15.71	—	—	8.561	Reddish-yellow	Finely crystalline	36,0 4	2	—	8	6	15	—	—	Ml.	
—	84.00	16 00	—	—	—	—	—	—	—	—	—	—	—	—	—	Bo.	Carriage wheel boxes.
—	83.30	16.70	—	—	—	—	—	—	—	—	—	—	—	—	—	Bo.	Jeweler's punches.
$SnCu_9$	82.81	17.19	—	—	8.462	Reddish-Yellow 2	Finely crystalline	34,048	3	—	5	7	14	—	—	Ml.	
—	82 50	17.50	—	—	8.792	Reddish-gray	Finely crystalline	36,200	—	0.32	—	—	—	—	—	U.S.B.	Strongest of series.
—	82.00	18.00	—	—	8.927	—	—	—	—	—	—	—	—	—	—	R.	Annealed and tempered.
$SnCu_8$	81.15	18.85	—	—	8.86	—	—	—	—	—	—	—	—	—	—	Ri.	
$SnCu_8$	81.10	18.90	—	—	8.459	Yellowish-red 2	Finely crystalline	39,648	4	—	4	10	13	—	—	Ml.	
—	—	—	80.43	19 57	8.953	—	—	—	—	—	—	—	—	—	—	Th.	Chinese gong.
—	80.00	2 .00	—	—	8.7	—	—	—	—	—	—	—	—	—	—	Bo.	Bells of Reichenhall, 300 years old.
—	80.00	20.00	—	—	—	—	—	35,739	—	—	—	—	—	—	—	Mus.	
—	8 .00	20.00	—	—	8.850	—	—	—	—	—	—	—	—	—	—	Ri.	Annealed and tempered.
—	80.00	20.00	—	—	8 9 5	—	—	—	—	—	—	—	—	—	—	Ri.	After repeated compression.
—	80.00	20.00	80.95	18.84	8.740	Reddish-gray	Finely granular	32,980	—	0.40	—	—	—	—	—	U.S.B.	
—	79.20	20.80	—	—	8.927	—	—	—	—	—	—	—	—	—	—	Ri.	Annealed and tempered.
$SnCu_7$	79.02	20.98	—	—	8.90	—	—	—	—	—	—	—	—	—	—	Ri.	
$SnCu_7$	78.97	21.03	—	—	8.728	Yellowish-red 1	Vitreous conchoidal	30,464	5	—	3	11	12	—	—	Ml.	
—	78.00	22.00	—	—	—	—	—	—	—	—	—	—	—	—	—	Bo.	Best bell-metal.
—	77.50	22.50	—	—	8.917	Pinkish-gray	Finely granular	24,650	—	0.03	—	—	—	—	—	U.S.B.	
$SnCu_6$	76.32	23.68	76.64	23.24	8.565	—	Smooth	22,010	—	0.02	—	—	—	—	—	U.S.B.	
$SnCu_6$	76.31	23 69	—	—	8.91	—	—	—	—	—	—	—	—	—	—	Ri.	
$SnCu_6$	76.29	23.71	—	—	8.750	Bluish-red	Vitreous	21,728	0	—	2	12	11	—	—	Ml.	
—	76.20	23.80	—	—	9.1(?)	—	—	—	—	—	—	—	—	—	—	Bo.	Church bell in Reichenhall, 600 years old.
—	75.20	24.80	—	—	—	—	—	—	—	—	—	—	—	—	—	Bo.	Swiss clock-bells, brittle.
—	75 00	25.00	—	—	—	—	—	—	—	—	—	—	—	—	—	W.	

Properties of the Alloys of Copper and Tin.—Continued.

Atomic formula.	Composition of original mixture.		Composition by analysis.		Specific gravity.	Color.	Fracture.	Tenacity, pounds per square inch.	Order of ductility (Mallet).	Relative ductility (Thurston).	Hardness (Mallet, and Calvert and Johnson).	Order of malleability (Mallet).	Order of fusibility (Mallet).	Conductivity for heat, silver=100.	Conductivity for electricity, silver=100.	Authority.	Remarks.
	Cu.	Sn.	Cu.	Sn.													
$SnCu_6$	72.91	27.09	—	—	8.87	Reddish-white	—	—	—	—	—	—	—	—	—	Ri.	
$SnCu_5$	72.90	27.10	—	—	8.965	—	—	—	—	—	Broke	—	—	—	—	C. J.	
$SnCu_5$	72.80	27.20	—	—	8.575	Bluish-red	Conchoidal	10,976	0	—	1	13	10	2 7	—	Ml.	
—	72.50	27.50	—	—	8.925	Reddish-white	"	6,493	—	0.003	—	—	—	—	—	U.S.B.	
—	70.00	30.00	69.84	29.89	8.932	White	"	5,585	—	0.008	—	—	—	—	—	U.S.B.	
—	68.82	31.18	—	—	—	—	—	—	—	—	—	—	—	—	—	Bo.	Mirror of telescope.
$SnCu_4$	68.28	31.72	—	—	8.80	—	—	—	—	—	—	—	—	—	—	Ri	
$SnCu_4$	68.27	31.73	—	—	8.948	—	—	—	—	—	Broke	—	—	—	—	C. J.	
$SnCu_4$	68 25	31.75	68.58	31.26	8.938	White	Conchoidal	1,620	—	—	—	—	—	15.5	—	U.S. B.	
$SnCu_4$	68.21	31.79	—	—	8.400	Ash-gray	"	1,568	0	—	6	14	9	—	—	Ml.	
—	68.21	31.79	—	—	—	—	—	—	—	—	—	—	—	—	—	Bo.	Mirror metal.
—	67.50	32.50	—	—	8.907	White	Conchoidal	2,536	—	0.009	—	—	—	—	—	U.S.B.	
—	66.67	33.33	—	—	—	Steel-gray	—	—	—	—	—	—	—	—	—	W.	Hard, uniform.
—	66.67	33.33	—	—	—	—	—	1,017	—	—	—	—	—	—	—	Mus.	
—	65.00	35.00	65.34	34.47	8.947	Bluish-gray	—	2,201	—	0 002	—	—	—	—	—	U.S.B.	
—	62.50	37.50	—	—	8.946	Dark gray	Radiated crystalline	1,561	—	0.001	—	—	—	—	—	U.S.B.	
$SnCu_3$	61.79	38 21	—	—	8.954	—	—	—	—	—	Broke	—	—	49.4	—	C. J.	
$SnCu_3$	61.79	38.21	—	—	8.96	—	—	—	—	—	—	—	—	—	—	Ri.	
$SnCu_3$	61.71	38.29	—	—	8.970	Dark gray	Rough, stony	688	—	0.003	—	—	—	—	—	U.S.B.	Greatest density, weakest.
$SnCu_3$	61.69	38.31	—	—	8.539	"	Tabular crystalline	1,120	0	—	7	16	8	—	—	Ml.	
—	60.00	40.00	—	—	—	—	—	—	—	—	—	—	—	—	—	Bo.	White bell-metal.
—	57.50	42.50	—	—	8.781	Light gray	Stony	1,377	—	0 001	—	—	—	—	—	U.S.B.	
Sn_5Cu_{12}	56.32	43.68	56.70	43.17	8.682	"	"	1,455	—	0.003	—	—	—	—	—	U.S.B.	
—	52.50	47.50	—	—	8.643	"	"	—	—	0.001	—	—	—	—	—	U.S.B.	Weakest under transverse stress.
$SnCu_2$	51.84	48.16	—	—	8.57	—	—	—	—	—	—	—	—	—	—	Ri.	
$SnCu_2$	—	—	—	—	8.512	—	—	—	—	—	—	—	—	—	—	Cr.	
$SnCu_2$	51.83	48.17	—	—	8 533	—	—	—	—	—	Broke	—	—	42.8	—	C. J.	
$SnCu_2$	51.80	48.20	51.62	48.09	8.56	Light gray	—	2 555	—	0.003	—	—	—	—	—	U.S.B.	Remarkable for liquation.
$SnCu_2$	51.75	48.25	—	—	8.416	Grayish-white	Vitreous conchoidal	3,808	0	—	9	15	7	—	—	Ml.	
—	50.00	50.00	—	—	—	—	—	725	—	—	—	—	—	—	—	Mus.	
—	50.00	50.00	—	—	8.79	Bluish-white	—	—	—	—	—	—	—	—	—	W.	Very slightly malleable.

Properties of the Alloys of Copper and Tin.—Continued.

Atomic formula.	Composition of original mixture.		Composition by analysis.		Specific gravity.	Color.	Fracture.	Tenacity, pounds per square inch.	Order of ductility (Mallet).	Relative ductility (Thurston).	Hardness (Mallet, and Calvert and Johnson).	Order of malleability (Mallet).	Order of fusibility (Mallet).	Conductivity for heat, silver=100.	Conductivity for electricity, silver=100.	Authority.	Remarks.
	Cu.	Sn.	Cu.	Sn.													
Sn_7Cu_2	47.95	52.05	47.61	52.14	8.442	Grayish-white	Fine grain	1,525	—	0.003	—	—	—	—	—	U.S.B.	
—	47.50	52.50	—	—	8.466	"	Crystal	2,407	—	0.003	—	—	—	—	—	U.S.B.	
Sn_2Cu_3	44.67	55.33	—	—	8.30	"	—	—	—	—	—	—	—	—	—	Ri.	
Sn_3Cu_3	44.63	55.37	44.52	55.28	8.312	"	Crystal	3,010	—	0.003	—	—	—	—	—	U.S.B.	
—	42.50	57.50	—	—	8.437	"	"	2,008	—	0.006	—	—	—	—	—	U.S.B.	
Sn_3Cu_4	41.74	58.26	42 38	57.30	8.302	"	"	3,910	—	0.007	—	—	—	—	—	U.S.B.	
—	40.00	60.00	—	—	—	—	—	—	—	—	—	—	—	—	—	Bo.	White bell-metal.
Sn_5Cu_6	39.20	60.80	38.37	61.32	8.182	Grayish-white	Crystal	2,820	—	0.005	—	—	—	—	—	U.S.B.	
—	37.50	62.50	—	—	8.101	"	"	2,400	—	0.004	—	—	—	—	—	U.S.B.	
SnCu	34.99	65.01	—	—	8.12	—	—	—	—	—	—	—	—	—	—	Ri.	
SnCu	34.98	65.02	—	—	7.992	—	—	—	—	—	Broke	—	—	41.5	—	C. J.	
SnCu	—	—	—	—	8.072	—	—	—	—	—	—	—	—	—	—	Cr.	
SnCu	34.95	65.05	34.22	65.80	8.0 3	Grayish-white	Crystal	3,371	—	0.005	—	—	—	—	—	U.S.B.	
SnCu	34.92	65.08	—	—	8.056	"	Tabular crystalline	3,136	0	—	11	9	6	—	—	Ml.	
—	33.33	66.67	—	—	—	White	—	—	—	—	—	—	—	—	—	W.	Brittle; uniform.
—	32.50	67.50	—	—	7.931	Grayish-white	Crystal	2,322	—	0.014	—	—	—	—	—	U.S.B.	
Sn_4Cu_3	28.72	71.28	25.85	74.80	7.918	"	"	1,618	—	0.011	—	—	—	—	—	T.	
—	27.50	72.50	—	—	7.915	"	"	4,380	—	0.018	—	—	—	—	—	T.	
—	25.00	75.00	—	—	7.813	Bluish-white	"	—	—	—	—	—	—	—	—	W.	
Sn_5Cu_3	24.38	75.62	23.35	76.29	7.835	Grayish-white	Finely crystalline	6,775	—	0.03	—	—	—	—	—	T.	
—	22.50	77.50	—	—	7.774	"	"	5,000	—	0.12	—	—	—	—	—	T.	
—	21.74	78.26	21.38	77.63	7.53	Whitish	—	—	—	—	—	—	—	—	—	W.	Yellow, greenish-white [shining.
Sn_2Cu	21.21	78.79	—	—	7.738	—	—	—	—	—	135.42	—	—	43.1	—	C. J.	
Sn_2Cu	21.21	78.79	—	—	7.74	—	—	—	—	—	—	—	—	—	—	Ri.	
Sn_2Cu	21.18	78.82	20.25	79.63	7.770	Grayish-white	Crystal	4,337	—	0.06	—	—	—	—	—	T.	
Sn_2Cu	21.15	78.85	—	—	7.387	"	Coarse crystal	8,736	0	—	12	8	5	—	—	Ml.	
Sn_5Cu_2	17.68	82.32	—	—	7.652	—	—	—	—	—	—	—	—	—	—	Cr.	
—	17.50	82.50	—	—	7.690	Grayish-white	Crystal	2,816	—	0.20	—	—	—	—	—	T.	
—	16.40	83 60	—	—	—	—	—	—	—	—	—	—	—	—	12.76	Ma.	
Sn_3Cu	15.21	84.79	—	—	7.53	—	—	—	—	—	—	—	—	—	—	Ri.	
Sn_3Cu	15.21	84.79	—	—	7.606	—	—	—	—	—	104.17	—	—	42.3	—	C. J.	
Sn_3Cu	15.19	84.81	15.08	84.62	7.657	Grayish-white	Crystal	6,520	—	0.92	—	—	—	—	—	T.	
Sn_3Cu	15.17	84.83	—	—	7.147	"	Coarsely crystalline	6,914	0	—	13	15	4	—	—	Ml.	
—	12.50	87.50	—	—	7.543	"	Crystal	3,798	—	4.71	—	—	—	—	—	T.	
Sn_4Cu	11.86	88.14	—	—	7.558	—	—	—	—	—	95.81	—	—	40.6	—	C. J,	

Properties of the Alloys of Copper and Tin.—Concluded.

Atomic formula	Composition of original mixture. Cu.	Sn.	Composition by analysis. Cu.	Sn.	Specific gravity.	Color.	Fracture.	Tenacity, pounds per square inch.	Order of ductility (Mallet).	Relative ductility (Thurston).	Hardness (Mallet, and Calvert and Johnson).	Order of malleability (Mallet).	Order of fusibility (Mallet).	Conductivity for heat, silver=100.	Conductivity for electricity, silver=100.	Authority.	Remarks.
$Sn_{12}Cu$	11.84	88.16	11.49	88.47	7.552	Grayish-white	Crystal	6,380	—	7.03	—	—	—	—	—	T.	Slightly malleable.
Sn_8Cu	11.84	88.16	—	—	7.50	—	—	—	—	—	—	—	—	—	—	Ri.	
Sn_4Cu	11.52	88.18	—	—	7.472	Grayish-white	Coarsely crystalline	6,944	8	—	14	4	3	39.6	—	Mi.	
Sn_5Cu	9.73	90.27	—	—	7.517	—	—	—	—	—	83.33	—	—	—	—	C. J.	
Sn_6Cu	9.73	90.27	—	—	7.52	—	—	—	—	—	—	—	—	—	—	Ri.	
Sn_7Cu	9.70	90.30	8.57	91.39	7.487	Grayish-white	Granular	6,450	—	23.47	15	3	2	—	—	T.	
Sn_8Cu	9.68	90.32	—	—	7.442	"	Earthy	3,360	6	—	—	—	—	—	—	Mi.	
Sn_9Cu	9.09	90.91	—	—	7.472	—	—	—	—	—	—	—	—	—	—	W.	
—	7.50	92.50	—	—	7.417	Grayish-white	Granular	6,076	—	40.06	—	—	—	—	12.03	U.S.B.	
$Sn_{12}Cu$	6.43	93.57	—	—	—	—	—	—	—	—	—	—	—	—	—	Ma.	
—	4.29	95.71	3.72	96.31	7.360	Grayish-white	Granular	4,780	—	56.77	—	—	—	—	—	U.S.B.	
$Sn_{16}Cu$	2.50	97.50	—	—	7.42	"	Fibrous	5,100	—	121.9	—	—	—	—	—	U.S.B.	
$Sn_{32}Cu$	1.11	98.89	0.74	99.02	7.305	"	"	3,650	—	133.9	—	—	—	—	—	U.S.B.	
$Sn_{96}Cu$	0.56	99.44	0.32	99.46	7.299	"	"	4,475	—	208.8	—	—	—	—	—	U.S.B.	
Sn	0	100.00	—	—	7.293	"	"	3,500	—	219.8	—	—	—	—	—	U.S.B.	
—	0	100.00	—	—	7.291	White	—	6,010	7	—	16	1	1	—	—	Mi.	
—	0	100.00	—	—	7.277	—	—	2,122	—	—	—	—	—	—	—	Wa.	
—	0	100.00	—	—	7.294	—	—	—	—	—	—	—	—	—	11.45	Ma.	
—	0	100.00	—	—	7.305	—	—	—	—	—	27	—	—	42.2	—	Cr.	
—	0	100.00	—	—	—	—	—	—	—	—	—	—	—	15.2	17.0	C. J.	
																We.	

LIST OF AUTHORITIES.

Bo.—Bolley. *Essais et Recherches Chimiques*, Paris, 1869, pp. 345, 348.
Cr.—Croockewit. *Erdmann's Journal*, XLV, 1848, pp. 87 to 93.
C. J.—Calvert and Johnson. *Specific Gravities*, *Phil. Mag.*, 1859, Vol. 18, pp. 354 to 359; *Hardness*, *Phil. Mag.*, 1859, Vol. 17, pp. 114 to 121; *Heat Conductivity*, *Phil. Trans.*, 1858, pp. 349 to 368.
De.—S. B. Dean. *Ordnance Notes*, No. XL. Washington, 1875.
La.—Lafond. *Dingler's Jour.*, 1855, Vol. 135, p. 269.
Ml.—Mallet. *Phil. Mag.*, 18 2, Vol. 21, pp. 66 to 68.
Ma.—Matthiessen. *Phil. Trans.*, 1860, p. 161; *ibid.*, 1864, pp. 167 to 200.
Mar.—Marchaud and Scheerer. Journal fuer Praktische Chemie, Vol. 27, p. 193 (Clark's "*Constants of Nature*").
Mus.—Muschenbroek. *Ure's Dictionary*, article "Alloy."
Ri.—Riche. *Annales de Chimie*, 1873, Vol. 20, pp. 351 to 419.
U. S. B.—*Report of Committee on Metallic Alloys of United States Board appointed to Test Iron, Steel, etc.*
T.—Thomas Tomson.—*Annales de Chimie*, 1814, Vol. 89, pp. 46 to 58.
W. Watt's *Dictionary of Chemistry*.
Wa.—Major Wade, United States Army. *Report on Experiments on Metals for Cannon*, Phil., Baird, 1856.
We.—Weidemann. *Phil. Mag.*, 1860, Vol. 19, pp. 243, 244.

Note on the table.—In the preceding table the figures of order of ductility, hardness, and fusibility are taken from Mallet's experiments on a series of 16 alloys, the figure 1 representing the maximum, and 16 the minimum, of the property. The ductility of the brittle metals is represented by Mallet as 0.

The relative ductility given in the table of the alloys experimented on by the U. S. Board is the proportionate extension of the exterior fibers of the pieces tested by torsion as determined by the autograph strain diagrams. It will be seen that the order of ductility differs widely from that given by Mallet.

The figures of relative hardness, on the authority of Calvert and Johnson, are those obtained by them by means of an indenting tool. The figures are on a scale in which cast-iron is rated at 1000. The word "broke" in this column indicates the fact that the alloy opposite which it occurs broke under the indenting tool, showing that the rela-

tive hardness could not be measured, but was considerably greater than that of cast-iron.

The figures of specific gravity show a fair agreement among the several authorities in the alloys containing more than 35 per cent. of tin, except those given by Mallet, which are in general very much lower than those by all other authorities. In the alloys containing less than 35 per cent. of tin there is a wide variation among all the different authorities, Mallet's figures, however, being generally lower than the others. Several of the figures of specific gravity have been selected from Riche's results of experiments on the effects of annealing, tempering and compression, which show that the latter especially tends to increase the specific gravity of all the alloys containing less than 20 per cent. tin, to about 8.95. This result is due merely to the closing-up of the blow-holes, thus diminishing the porosity. The specific gravity of 8.953 was obtained by Major Wade by casting a small bar in a cold iron mould from the same metal, which gave a specific gravity of only 8.313 when cast in the form of a small bar in a clay mould. The former result is exceptionally high, and indicates the probability that every circumstance of the melting, pouring, casting, and cooling was favorable to the exclusion of the gas which forms blow-holes and to the formation of perfectly compact metal.

The figures of tenacity given by Mallet, Muschenbroek, and Wade agree with those found in the experiments as closely as could be expected from the very variable strengths of alloys of the same composition which have been found by all experimenters.

Mallet's figure for copper, 24.6 tons or 55,104 pounds, is certainly much too high for cast copper; the piece which he tested was probably rolled or perhaps drawn into wire. Haswell's Pocket Book gives the following as the tensile strength of copper; the names of the authorities are not given:—

	Pounds per square inch.
Copper, wrought	34,000
Copper, rolled	36,000
Copper, cast (American)	24,250
Copper, wire	61,200
Copper, bolt	36,800

The strength of gun-bronze, as found in the guns, is not given in the table, which is designed to compare the various authorities on the tenacities of the alloys only as cast under ordinary conditions, and not when compressed, rolled, or cast under pressure.

CHAPTER VIII.

ALLOYS OF COPPER WITH OTHER METALS.

In the preceding chapters the alloys of copper have been described which on account of their easy preparation and the larger proportion of the metals which are combined with the copper are in general use. There are, however, a number of other copper alloys which, though at present seldom employed, possess properties deserving attention.

Copper-arsenic alloys.—Arsenic imparts to copper a very beautiful white color and great hardness and brittleness. Before German silver was known these alloys known as *white copper*, *white tombac*, *argent haché*, *Chinese pétong*, etc., were sometimes used for the manufacture of cast articles which were not to come in contact with iron. On exposure to the air these alloys, however, retain their white color for a short time only, and acquire a brownish tinge. On account of this, as well as the poisonous character of arsenic and the difficulty of working them, these alloys are very little used at the present time.

A white, brittle, lustrous alloy capable of taking a high polish is obtained by pressing a mixture of 70 parts copper in the form of fine shavings, and 30 of white arsenic into a crucible, and melting the mixture under a surface coat of glass in a furnace of good draught. *Or* by melting copper with white arsenic and black flux, *or* by melting 16 parts copper and 1 part calcium arsenate under a cover of borax, coal dust and glass powder.

Copper-lead alloys. An addition of lead to copper renders it softer and more ductile. Alloys of copper and lead are subject to separation or liquation, the lead separating out and leaving the copper in a porous mass, especially

if the alloy is not quickly solidified. In preparing the alloys the copper is melted down under a cover of charcoal dust, the fire is then made as hot as possible and the lead quickly introduced into the overheated copper. As soon as all is melted, stir several times with an iron rod to make the alloy homogeneous, and quickly pour the liquid mass into cold metallic moulds. On account of the above-mentioned liquation it is difficult to obtain faultless large castings of these alloys, and hence they are cast into thin plates, which are subsequently rolled out into sheets. The alloy forms a metal of gray color, brittle and of feeble affinity. An alloy of copper 4 parts and lead 1 is sometimes used for large type.

For sheets and plates requiring no great durability, Guettier recommends an alloy of equal parts lead and copper. For hard solder Domingo recommends an alloy of copper 15.16 parts and lead 20.

Copper-iron alloys. In ancient times such alloys in the form of black copper appear to have been employed for castings. A statue of Buddha from Hindostan, about 3500 years old, contains, according to Forbes, 91.502 copper, 7.591 iron, 0.021 silver, 0.005 gold, 0.079 arsenic, 0.510 sulphur, 0.292 insoluble matter, and traces of nickel and manganese. An alloy of copper 2 and iron 1 possesses great strength, which decreases with the increase in iron, while the hardness increases. An addition of 3 to 4 per cent. copper to malleable iron gave, according to Höltzer, with decreased strength an elongation of 22.5 per cent. and a decrease in the cross-section of 51 per cent. According to Billings iron with 2 per cent. copper gives a very red-short, dark gray, granular alloy. However, according to the more recent investigations of Ball and Wingham, copper in iron is not so dangerous as generally supposed, and the red-shortness ascribed to copper may be due to sulphur occurring in the ores. The authors named found cupriferous steel stronger, but harder, than steel free from copper.

Copper-steel.—Some years ago M. Henry Schneider, of Cruezot, France, took out patents for the manufacture of alloys of iron and copper, and steel and copper. In the patent specifications it is stated the alloy of cast iron and copper can be made in a crucible, cupola, or open-hearth furnace. "The furnace is charged with copper scrap and cast iron mixed between layers of coke, or if a cuprous coke be employed then the cast iron is laid in alternate layers with it, and a layer of anthracite is preferably laid over the whole. The alloy thus formed contains, generally, from five to twenty per cent. of copper, according to the purpose for which it is to be employed, and it is remarkable for its great strength, tenacity and malleability—properties which may be still further developed by chilling or tempering."*

The alloy thus formed is charged into the bed of a furnace, with the ordinary ingredients used in the manufacture of steel, preferably under a layer of anthracite, to avoid oxidation. It is important that the copper be introduced at as early a stage in the process as possible. The said alloy may be introduced either while melted or in its hardened condition, or it may be prepared in the furnace itself, where the operation of manufacturing the steel is carried on. In the latter case, the bed of anthracite is first prepared and the copper placed thereon with a suitable quantity of cast or pig iron. The whole is then covered with anthracite, in order to protect the metal from contact with the air during fusion. When the charge is melted, the excess of anthracite is removed and successive charges of iron or scrap added, the operation being then continued in the ordinary way, care being taken to continually protect the bath from oxidation by means of a layer of slag or cinder, which may be renewed as required, and also to prevent red-shortness in the metal before the final introduction of the recarbonizing and manganiferous silico-spiegel iron or ferro-manganese.

*U. S. Patent 415,656, Nov. 19. 1889.

The steel produced by this means contains from two to four per cent. of copper.

It is stated in the patent specifications that the steels alloyed with copper are especially useful in the manufacture of ordnance, armor-plate, gun-barrels, projectiles and for other military purposes, or in the manufacture of commercial bars, sheets, etc.*

In view of the remarkable elastic limit of copper-steel while maintaining at the same time a very considerable elongation, Mr. F. Lynwood Garrison † is of the opinion that it would not be surprising if its use became very extensive in the arts. It has the advantage over aluminium, nickel and tungsten steels in being cheaper to manufacture.

Alloys of copper and much zinc. Pure zinc fouls the cut of files, and to decrease this evil it is mixed with small quantities (1 to 10 per cent.) of copper or iron, or of both metals. For cheaper bearing metals better able to resist friction, which are harder and stronger than pure zinc and have but a slight coefficient of friction, zinc may be combined with tin, a little copper, and some antimony. The annexed table gives the composition of a few of such alloys:

	Zinc.	Copper.	Anti-mony.	Tin.	Lead.	Iron.
English bearing metal, very good, ½ brass	80	5.5	—	14.5	—	—
Same for rapidly revolving shafts	76.14	5.69	—	17.47	—	—
Rolls for calico printing	78.3	5.6	—	15.8	—	—
Metal for pump cocks, which does not deposit verdegris	72	7	—	21	—	—
Pierrot's metal	83.33	2.27	3.79	7.57	3.03	—
Kniess' bearing metal	40	3	—	15	42	—
Wagner's bearing metal for steam engines	24	0.5	3	18	14.5	0.5
Dunlevie and Jones' bearing metal	52	1.6	0.4	46	—	—

* U. S. Patent 415,654, Nov. 19, 1889. The British Patents Nos. 16,568 and 16,569, 1888, seem to have been abandoned in 1890.

† Jour. of the Franklin Inst., Sept., 1891.

Dunlevie and Jones' bearing metal is prepared by melting the copper in a crucible, adding $\frac{1}{7}$ of the tin and the antimony, and pouring into an ingot-mold. In another crucible the zinc is melted together with the rest of the tin, and, after adding the first alloy, the whole is again melted.

Alloys which can be filed are composed of zinc 90 to 99 and copper 1 to 10; *or* zinc 98 to 99.8 and iron 0.2 to 2; *or* zinc 97, copper 2.5, and iron 0.5; *or* zinc 68, copper 11, tin 21.

Manganese-brass.—According to Parkes, copper 70, manganese 30 and zinc 20 to 30 give a silver-like alloy which can be forged and rolled at a red heat. If the alloy is not required to stand a high temperature the composition is: Copper 49, manganese 21, iron 5 to 10, and zinc 5 to 10. *For soldering the alloy* the following composition is suitable: Copper 7, manganese 3, silver 1 to 2,

For coins, copper 65, manganese 25 and zinc 10 may be melted together, *or* copper 65, manganese 15 to 20, zinc 10, and nickel 5 to 10.

Copper-tungsten alloys.—Copper and tungsten unite, according to Biermann, to an alloy with 10 per cent. tungsten which combines hardness and elasticity with toughness, and is suitable for axle bearings and telegraph wires. Tungsten-copper combines also with other metals. Biermann prepared an alloy with iron 66, nickel 23, tungsten 4, and copper 5. According to Pufahl, Biermann's tungsten bronze contains copper 95.39, tin 3.04 and tungsten 1.57.

Copper-cobalt alloys.—These alloys show a red color and a fracture resembling that of pure copper. They are distinguished by great ductility and tenacity, and can be forged and stretched in the heat, and cannot be hardened. They are prepared by melting together copper and cobalt in a crucible under a cover of boric acid and charcoal. An alloy cast in grains, which is attracted by a magnet, is composed

of cobalt 48.20 per cent., nickel 1, copper 50.26, and iron 0.46. It is red, while an alloy containing equal proportions of nickel and copper shows a white color. Alloys with 1 to 6 per cent. of cobalt can be as readily forged, stretched, and rolled hot as copper, but are considerably tougher. An alloy with 5 per cent. cobalt shows especially valuable properties; it is non-oxidizable and ductile like copper, elastic and tough like iron, and will no doubt be applied to many purposes.

Cobalt bronze of Wiggin & Co., of Birmingham, is an alloy of copper, cobalt, zinc, tin or lead, and is said to possess all the properties of pure cobalt.

Copper-magnesium alloys. — According to Gräzel, an alloy of copper and magnesium is used as addition to tombac castings, and when of a pale red color and quite brittle contains, according to Pufahl, copper 89.31, magnesium 10.18, aluminium 0.05, nickel 0.21, lead 0.08 and iron 0.07.

According to Warren, alloys of copper with magnesium as regards general properties do not surpass the other usual copper alloys, which can be more readily prepared. An alloy with 11 per cent. magnesium has a brass-like appearance. is very brittle, and when melted together with copper gives alloys which with an increase in the content of copper become less brittle. An alloy with 4 per cent. magnesium resembles an actual bronze in appearance and physical properties; 1½ per cent. magnesium makes the copper somewhat lighter in color, and harder. The French *Societé industrielle et commercial des metaux* has introduced alloys of copper with iron, nickel and zinc-magnesium.

Copper-antimony alloys.—According to Held, a malleable gold-like alloy is obtained by adding to 100 parts of melted copper 6 parts of antimony, and, when liquefaction is complete, some wood ashes, calcareous spar and magnesium to remove porosity. The alloy is said to be stronger than gold.

Melted together in equal parts copper and antimony give a hard combination of a beautiful violet color suitable for fancy articles.

Mira metal.—The alloy known by this name is distinguished by great resistance towards acids and is, therefore, especially suitable for cocks, pipes, etc., which come in contact with acid liquids. Mira metal contains according to analysis: Copper 74.755, zinc 0.615, lead 16.350, tin 0.910, iron 0.430, nickel and cobalt 0.240, antimony 6.785.

CHAPTER IX.

TIN-ALLOYS.

Tin is distinguished by its beautiful white color and by its permanency when exposed to the air. Although soft in itself, it has the property of hardening many other soft metals. It is but seldom worked by itself but, as a rule, alloyed with another metal whereby its comparatively slight hardness is increased, and it also becomes more thinly-fluid and more capable of being cast. The metal most frequently used for alloying with tin is lead, which combines with it without difficulty in all proportions by weight.

Tin-Lead Alloys.—These alloys are easily made. Lead added to tin increases its malleability and ductility while its properties are not materially impaired; its tenacity is however decreased. Difficult to break even after successive bendings, tin becomes more brittle when alloyed with lead. The fracture is then more marked than that of lead, whatever may be the proportions in the alloy, the latter metal being more readily separated than tin but requiring, nevertheless, to be torn asunder. The strongest alloy of tin and lead is produced by alloying tin 3 parts and lead 1, the density of this alloy being 8. According to Watson, the densities of tin-lead alloys are as follows:—

0	1	11.3
10	1	7.2
32	1	7.3
16	1	7.4
8	1	7.6
4	1	7.8
2	1	8.2
1	1	8.8

Alloys of tin and lead were formerly much used in the

manufacture of domestic utensils. They are, however, not suitable for this purpose, on account of the solubility and poisonous properties of the lead. Under no circumstances should an alloy of tin and lead used in the manufacture of domestic utensils contain more than 10 to 15 per cent. of lead. Such an alloy is not sensibly attacked by vinegar and fruit acids. But unfortunately there are cases in which the so-called tin contains as much as one-third of its weight of lead.

Alloys containing from 10 to 15 per cent. of lead have a beautiful white color, are considerably harder than pure tin, and much cheaper. Many alloys of tin and lead have an especially lustrous appearance and are used for stage-jewelry and mirrors for reflecting the light of lamps, etc. An especially lustrous alloy is known under the name of *Fahlun brilliants*. It is used for stage jewelry and consists of tin 29 parts, lead 19. The alloy is poured into moulds faceted in the same manner as diamonds. Seen in an artificial light, the pieces of metal thus cast are so brilliant as to produce the effect of diamonds. Other alloys of tin and lead of some importance are those used in the manufacture of toys (tin soldiers). They must fill the moulds well and be cheap, and, consequently, as much as 50 per cent. of lead is used. With the use of sharp iron or brass moulds such an alloy yields good castings. Toys can also be prepared from type-metal, which is even cheaper than alloys of tin and lead, but has the disadvantage of readily breaking on sharply bending the articles.

In the following table the melting points of alloys of tin and lead as determined by Messrs. Parkes and Martin are given :—

Composition.		Melting points. Degrees F.	Composition.		Melting points. Degrees F.
Tin.	Lead.		Tin.	Lead.	
4	4	372°	4	28	527°
6	4	336	4	30	530
8	4	340	4	32	532
10	4	348	4	34	535
12	4	336	4	36	538
14	4	362	4	38	540
16	4	367	4	40	542
18	4	372	4	42	544
20	4	378	4	44	546
22	4	380	4	46	548
24	4	382	4	48	550
4	4	392	4	50	551
4	6	412	4	52	552
4	8	442	4	54	554
4	10	470	4	56	555
4	12	482	4	58	556
4	14	490	4	60	557
4	16	498	4	62	557
4	18	505	4	64	557
4	20	512	4	66	557
4	22	517	4	68	557
4	24	519	4	70	558
4	26	523			

For baths used by cutlers and others in tempering and heating steel articles, Parkes and Martin propose the following alloys:—

No.	Use.	Composition.		Melting points. Degrees F.
		Lead.	Tin.	
1	Lancets	7	4	420°
2	Other surgical instruments	7½	4	430
3	Razors	8	4	442
4	Pen-knives	8½	4	450
5	Knives, scalpels, etc	10	4	470
6	Chisels, garden knives	14	4	490
7	Hatchets	19	4	509
8	Table knives	30	4	530
9	Swords, watch springs	48	4	550
10	Large springs, small saws	50	4	558
11	Hand saws	Oil boiling.		600
12	Articles of low temper	1	4	612

Britannia Metal.

The alloy known under this name consists principally of tin alloyed with antimony. Many varieties contain only these two metals and may be considered tin hardened by antimony. Other alloys, also called Britannia metal, contain, however, in addition, certain quantities of copper, sometimes lead, and occasionally, though rarely, bismuth.

The Pewterer's Company of England, which has been an incorporated society ever since the reign of Edward IV. (1474), in 1772 attempted to regulate the quality of pewter wares by permitting enough lead to bring the density of pewter from $\frac{1835}{1820}$ to $\frac{1985}{1820}$, that of tin. Persons who departed from this regulation were liable to expulsion from the guild, but it has been so greatly disregarded as to have very little effect in keeping up the standard of pewter.

Britannia metal has always a silvery color with a bluish tinge, and, on account of its hardness, takes a fine polish, which it retains on exposure to the air. Though it is quite hard, in strength it only slightly surpasses tin. Good Britannia metal shows a fine-grained, jagged fracture; if the fracture be quite coarse and strongly crystalline the alloy contains too much antimony, and, as a rule, is too brittle to be worked to advantage.

Even with a correct composition, the brittleness of Britannia metal is such that in rolling it out to sheet the edges generally become full of cracks. A content of iron or zinc increases this brittleness to a considerable extent, and, in preparing an alloy to be rolled out into sheet or to be used for stamped articles, great care must be had to have the metals to be used entirely free from iron or zinc. A content of copper increases the ductility of Britannia metal, but decreases its fusibility, which is one of its most valuable properties, and besides gives to the color a strong yellowish cast. An addition of lead is of advantage especially to metal to be principally used for castings, it becoming more fusible thereby and filling out the moulds

better, but its color acquires a strong brownish cast, and articles manufactured from it lose their luster on exposure to the air much more quickly than those containing no lead.

A large content of antimony, to be sure, imparts great hardness and a permanent brilliant luster to Britannia metal, but it also decreases its ductility. And, moreover, the antimony possessing poisonous properties, its use must be restricted, especially if the alloy is to be employed in the manufacture of domestic utensils, such as coffee and tea pots, etc. It need scarcely be said that for sanitary reasons the antimony must be free from arsenic, and besides, a very small content of it renders the alloy extremely brittle, and articles manufactured from it tarnish quickly, especially on exposure to moist air. Alloys consisting of tin and antimony alone would seem to deserve the preference, and a composition of tin 90 parts, antimony 10, can be especially recommended as regards resistance to chemical influences and for its facility of working.

For most purposes, not requiring a special degree of hardness, this alloy is the most suitable, it being readily fusible and filling the moulds out well. For articles subjected to constant wear a harder alloy is required.

The following table shows the composition of several varieties of Britannia metal :—

Britannia Metal.	Parts.					
	Tin.	Antimony.	Copper.	Zinc.	Lead.	Bismuth.
English	81.90	16.25	1.84	—	—	—
"	90.62	7.81	1.46	—	—	—
"	90.1	6.3	3.1	0.5	—	—
"	85.4	9.66	0.81	3.06	—	—
Pewter	81.2	5.7	1.60	—	1.15	—
"	89.3	7.6	1.8	—	1.8	—
"	83.30	6.60	1.60	3.06	—	1.60
Tutania	91.4	—	0.7	0.3	7.6	—
Queen's metal	88.5	7.1	3.5	0.9	—	—
German	72	24	4	—	—	—
"	84	9	2	5	—	—
" (cast)	20	64	10	6	—	—
Malleable (cast)	48	—	3	48	—	1
Birmingham (sheet)	90.60	7.80	1.50	—	—	—
" (cast)	90.71	9.20	0.09	—	—	—
Karmarsch's	85.0	5.0	3.60	1.40	—	1.60
Koeller's	85.70	10.40	1.00	—	—	1.80
Wagner's (fine)	85.64	9.66	0.81	3.06	—	0.83

Britannia ware made in Sheffield is often composed of block tin 3½ parts, antimony 28, copper 8, brass 8.

Dr. Carl Karmarsch, who thoroughly studied the properties of Britannia metal, says that the specific gravity of the alloy is 7.339 for laminated sheets, and 7.361 for casting. He explains this anomaly by the fact that the molecules, under the action of the rolls, have a tendency to become separated, their softness and malleability not being great enough to allow of a regular and uniform compression. This is not an isolated fact. M. LeBrun has also found a lower specific gravity for certain alloys of copper and zinc which had been laminated or hammered.

Britannia metal is prepared by first melting the copper by itself, then adding a portion of the tin and the entire quantity of the antimony. The fire can then be quickly moderated, because the new alloy has a much lower melting point than copper.

The last quantity of tin is finally added, and the alloy un-

interruptedly stirred for some time to make it thoroughly homogeneous.

Britannia metal can be brought into determined shapes by pressing and rolling, which will be referred to later on, but it being always to some extent brittle, it is preferred to prepare many articles by direct casting. To obtain clean and beautiful castings, requiring but little after-manipulation, it is best to use brass moulds. Before casting, the moulds have to be strongly heated and the interior lined with a special coating to prevent the alloy from adhering. This is effected by means of a mixture of lamp-black and oil of turpentine, or by lamp-black alone, and, though the first process is the more simple and convenient, the latter is preferable, especially for casting fine articles. The moulds can be so coated as to be beautiful and uniform by using an ordinary lamp, similar to a spirit lamp, filled with oil of turpentine. By holding the cold mould over the dull flame of such a lamp, it becomes coated with a delicate film of a velvety black soot, which, while it preserves all the fine lines of the mould, prevents the alloy from adhering.

Instead of lamp-black, some manufacturers use finely elutriated reddle or red chalk mixed to a uniform mass with water. With moulds having many small, and at the same time, deep turns, it is difficult perfectly to coat the inside with the protecting mass, and the coating with lamp-black is decidedly to be preferred.

With ordinary moulds it is, of course, impossible to cast an article which is to have a certain shape, in one piece. The different parts are consequently cast separately, and subsequently put together with a solder of a color as nearly like that of the metal as possible. Such articles can, however, be also cast in one piece. We will take, for example, an article frequently made of Britannia metal: a coffee-pot, whose shape is such that it must consist of several pieces. To cast it in one piece, the mould must be so constructed that it can be completely removed from the finished castings.

The separate parts of the mould having been coated with lamp-black, or reddle, are put together, and the whole heated nearly to the temperature of the melted Britannia metal. The latter is then poured into the mould until it seems entirely filled. After waiting until it may be supposed that a sufficiently thick layer of metal is solidified, the mould is quickly turned over to allow the still liquid portion of the metal to run out.

In order to obtain castings of the right condition, this mode of procedure requires considerable practical skill, it being necessary to hit the exact moment at which the layer of metal has acquired the required thickness, and before succeeding the operator must be prepared to meet with many failures. But by noting by means of a watch the time allowed to pass between pouring the metal into the mould, and pouring the still liquid portion out, the exact time required for the formation of a sufficiently thick layer will soon be learned.

The inside of the articles obtained by the above mode of casting is sometimes roughly crystalline. This is due to the metal beginning to crystallize, and the corners and edges of the small crystals being exposed by pouring out the liquid portion of the metal. Care must therefore be had to use for such casting an alloy giving a fine-grained mass. The interior of the articles, as far as accessible, can also be smoothed, while the article is still in the mould, with a burnishing stone or burnisher.

For articles to be made by stamping or other mechanical processes, the alloy resulting from melting the metals together is ladled into cast-iron boxes, and the slabs thus made are subsequently rolled into sheet. Spherical vessels are usually "spun up" in halves, which are then united by soldering, and smaller articles are generally pressed in moulds by a stamping press of very simple construction.

Cast or stamped Britannia metal has always an unsightly gray-white appearance, the innumerable small crystals of

which the surface of the article is composed preventing a complete reflection of the light. The articles must, therefore, be polished, which is effected with a burnisher, or, if their shape permits, upon the lathe by means of wooden disks covered with leather rubbed with emery.

A great many articles of Britannia metal are at the present time electro-plated with silver, the same as objects of German silver, which are so well manufactured in England, Germany, and this country, that it is difficult to distinguish them from pure silver. In some cases the Britannia metal is electro-plated with tombac.

Biddery-metal.—The name of this alloy is derived from Biddery, a city in the East Indies. It may be classed among the alloys known under the collective term of Britannia metal, but differs from it in containing lead instead of antimony.

Genuine Indian Biddery metal, which is frequently imitated in England, consists of—

	Parts.	
	I.	II.
Copper	3.5	11.4
Zinc	93.4	84.3
Tin	—	1.4
Lead	3.1	2.9

According to Dr. Hamilton, who had occasion to witness the operation, 123.6 parts of zinc, 4.6 of copper, and 4.14 of lead, together with a mixture of resin and wax to prevent oxidation, are melted together in a crucible. The fused metal is poured into clay moulds and the articles finished with the lathe. The Indian artists impart to the articles a beautiful velvety-black color by treatment with a solution of sulphate of copper, and decorate the surface in a very peculiar and original manner. By means of a graver, lines forming frequently very artistic designs, are cut into the surface. The lines are then inlaid with fine gold and silver wire, pressed in by means of a burnishing tool, after

which the articles are carefully polished. The beauty of the black coating being somewhat marred by the manipulation, is restored by treating the articles with a solution of sulphate of copper, sal ammoniac, and saltpetre, and finally polishing with very fine polishing agents.

The finished articles have a peculiar appearance, the gold and silver designs upon a velvety-black ground presenting frequently a striking resemblance to an embroidery executed in gold and silver threads upon black velvet.

There are several other alloys somewhat resembling Britannia metal which are known under various names. Of these we mention:—

Ashberry metal.—It is composed of—

	Parts.	
	I.	II.
Copper	2.0	3.0
Tin	80.0	79.0
Antimony	14.0	15.0
Zinc	1.0	2.0
Nickel	2.0	1.0
Aluminium	1.0	—

Minofor metal.—This alloy is composed of—

	Parts.	
	I.	II.
Copper	3.26	4
Tin	67.53	66
Antimony	17.00	20
Zinc	8.94	9
Iron	—	1

This alloy, as well as the Ashberry metal, is employed for making forks and spoons, coffee-pots, tea-pots, and all similar articles generally made of ordinary Britannia metal, composed of 9 parts of tin and 1 of antimony. Britannia metal in fact surpasses both the Ashberry and Minofor metals in beauty, but the latter are harder.

English metal is a more complex alloy and is composed

of: Tin 88 parts, pure copper 2, brass (copper 75, zinc 25) 2, nickel 2, bismuth 1, antimony 8, tungsten 2.

White Metals. Bearing Metals.

The so-called white metals contain varying quantities of tin, copper and antimony. Sometimes the latter is replaced by zinc, the composition in this case approaching more or less that of statuary bronze. A simultaneous use of zinc and antimony occurs but seldom; there are further some alloys which contain iron or lead besides the mentioned metals. A combination of many metals to one and the same alloy does not seem especially practicable, since our knowledge of the alloys has scarcely reached such a point as to enable us to determine with absolute certainty how three metals in various proportions of mixture behave towards each other, and we are still less able to state with accuracy the behavior of alloys in the preparation of which four, five, or even six metals are used. Besides practical experience has shown such alloys to be frequently of no value, and are simply recommended by some persons in order to make a market for a new product.

The so-called white metals serve almost exclusively for bearings, some compositions used for the same purpose having been already given on page 280. In mechanics a very exact line is drawn between the various kinds of bearings, and they can be chiefly divided into two large groups: Red-brass bearings and white-metal bearings. The red-brass bearings are distinguished by great hardness and power of resistance, and are principally used for bearings of heavily-loaded and rapidly-revolving axles. For bearings of axles of large, heavy fly-wheels revolving at great speed bearings of red brass are also preferable to white metal, though they are more expensive.

White metals are cheaper than red-brass alloys, and have a lower melting point, so that a worn-out bearing can be readily remelted and replaced by a new one, while with red

brass these operations are connected with much more trouble and expense. White-metal bearings possess still another property which makes them almost indispensable for certain purposes. If, for instance, the shaft resting in the bearing does not run perfectly quiet, the consequence of the use of a red-brass bearing will be that either the axle or the bearing, according to whether the one is harder than the other, is subjected to great wear, and this will in a short time increase to such an extent that the axle in revolving will swerve considerably. By using, however, for these purposes white-metal bearings of a sufficient degree of softness, the harder axle by pressing into the softer bearing runs more quietly for a longer time than if the latter consists of red-brass. The bearing, of course wears out as quickly, but this is of little importance since the expense of replacing it is comparatively small.

White metal bearings contain a preponderating quantity of tin; the degree of hardness of such alloys depends chiefly on the content of copper, those containing certain quantities of it being, as a rule, the strongest and most capable of resistance. The tin can, however, be also considerably hardened by the use of antimony, and such bearings are frequently used at the present time, they being much cheaper than those containing copper, though they are not so strong, and generally quite brittle, so that they frequently break.

By a metallographic examination* of congealed white metal of tin, antimony and copper, three different constituents can be distinguished.

1. Acicular crystals of a chemical combination of copper with tin according to the formula CuSn with about 35 per cent. copper and 65 per cent. tin, which are first separated from the liquid solution. They are the hardest constituents and crumble readily, leaving behind shallow, sharp-edged

*Charpy. Bulletin de la Société d' Encouragement 1898 and 1899.

depressions which, according to Behrens, promote the distribution and adhesion of the lubricant.

2. Cubical crystals of a tin-antimony alloy, harder than tin, but less hard and brittle than the above-mentioned copper-tin crystals, and than antimony.

3. Nearly pure tin as eutectic alloy enclosing the previously mentioned crystals. It is soft and plastic. According to Charpy, this yielding property of the alloy is of importance for decreasing friction in case the axle or journal is not accurately placed in the bearing. The latter adapts itself to the shape of the axle or journal, while a disproportionate influence is exerted upon the harder bronze bearings, the places which are more heavily loaded undergoing greater friction and wear.

When the bearings run hot the structure of the alloy becomes more coarsely crystalline and its behavior is less favorable.

The proportions by weight of the constituents of white metal vary very much. Tin is the most expensive of the metals entering into the compositions and, if for this reason, there should be the temptation of limiting its content and replacing it by lead, it must be considered that an alloy rich in lead is less hard than one rich in tin, and that an attempt to overcome this drawback by increasing the content of antimony would cause increased brittleness and hence a tendency of the parts towards breaking. An increase in the content of copper above a certain, quite low, proportion—about 5 per cent.—would not only increase the brittleness but also the melting point, and hence be doubly injurious.

For the white metal bearings of the Berlin Railroad 4 lbs. of copper are first melted; to this are added 8 lbs. of antimony and finally 24 lbs. of pure tin. The alloy is cast in plates 15 millimeters (0.59 inch) thick, and 40 lbs. of these are melted together with 40 lbs. of tin, overheating being as far as possible avoided, and again cast in plates,

which are now ready for use. The alloy therefore contains about 83 per cent. tin, 11 per cent. antimony, and 6 per cent. copper. It is of importance that the metals are as pure as possible, and especially contain no lead and zinc, and that larger quantities of metal should not be melted at one time.

The bearing metal used by the Austrian Northwest Railroad is of a similar composition, it containing tin 82 parts, antimony 12, copper 6.

In the annexed table will be found the compositions of the more frequently used compounds for bearings. From the many receipts given, those have been selected which differ in regard to hardness and wear. As will be seen, iron is only used in rare cases, and the compositions containing lead find but little application, experience having shown that the strength of the alloy is considerably decreased by an addition of lead.

In modern times bearings of soft metals are frequently replaced by such as consist of a metal whose hardness is almost equal to that of which the axle is made, phosphor-bronze being often used for this purpose, as it can be readily obtained so hard as to equal in that respect an axle of wrought or cast-steel. The metal is then used in a very thin layer, and serves, so to say, to fill out the small interspaces formed by wear on the axle and bearing, the latter consisting simply of an alloy of tin and lead. Such bearings, though very durable, are rather expensive, and can only be used for larger machines. For smaller machines bearings of white metal are generally preferred, and, if the axles are not too heavily loaded, do excellent service.

White metals for bearings.

	Parts.					
	Tin.	Antimony.	Zinc.	Iron.	Lead.	Copper.
German, for light loads..	85	10	—	—	—	5
" " ..	82	11	—	—	—	7
" " ..	80	12	—	—	—	8
" " ..	76	17	—	—	—	7
" " ..	3	1	5	—	3	1
" heavy loads.	90	8	—	—	—	2
" " .	86.81	7.62	—	—	—	5.57
English, for heavy loads.	17.47	—	76.14	—	—	5.62
" medium loads	76.7	15.5	—	—	—	7.8
" "	72.0	26.0	—	—	—	2.0
For mills	15	—	40	—	42	3
"	—	1	5	—	5	—
"	—	1	10	—	2	—
For heavy axles	72.7	18.2	—	—	—	9.1
" "	38	6	47	—	4	1
For rapidly revolving axles.....	17	77	—	—	—	6
Bearings of great hardness	5	—	—	70	—	2.5
Bearings of great hardness	12	82	2	—	—	4
Bearings (cheap).....	2	2	88	—	—	8
" "	1.5	1.5	90	—	—	7
For railroads—						
Prussia	91	6	—	—	—	3
"	85	10	—	—	—	5
"	80	12	—	—	—	8
Prussian and Hanoverian railroads approved under the heaviest pressure	86.81	7.62	—	—	—	5.57
Bavaria, durable cold running	90	8	—	—	—	2
Austria government railroad	90	7	—	—	—	3
Distributing slide valves.	83.2	11.2	—	—	—	5.6
Railroad cars and larger machines	—	16	—	—	84	—
Railroad cars, harder and stronger	20	20	—	—	60	—
	—	12	—	8	80	—

Babbitt's anti-friction metal.—The original Babbitt metal is made by melting together 4 parts by weight of copper, 12 of Banca tin, 8 of antimony regulus, and adding 12 parts by weight of tin after fusion. The antimony is added

to the first portion of tin, and the copper is introduced after taking the melting pot from the fire and before pouring into the mould. This alloy is called hardening. The "lining metal" consists of this hardening melted together with twice its weight of tin, thus making it consist of 3.7 parts copper, 7.4 parts antimony and 88.9 parts tin. The bearing to be lined is cast with a shallow recess to receive the Babbitt metal. The portion to be tinned is washed with alcohol and powdered with sal ammoniac, and those surfaces which are not to receive the lining metal are to be covered with a clay wash. The portion to be tinned is then warmed sufficiently to volatilize a part of the sal ammoniac, and then tinned. The lining is next cast in between a former, which takes the place of the journal and the bearing.

The German Admiralty specifications for Babbitt metal require 6 parts of tin to be combined with 1 part of copper, while other 6 parts of tin are to be alloyed with 1 part of antimony in a separate crucible. When both of these alloys are thoroughly liquified, they are brought together by pouring the one into the other, and mixing thoroughly. The alloy thus obtained is then poured into ingots, and remelted before being used for filling bushes, or interspacing slide valves.

A small percentage of aluminium added to Babbitt metal gives very superior results over the ordinary Babbitt metal. It has been found that the influence of the aluminium upon the ordinary tin-antimony-copper Babbitt is to very considerably increase the durability and wearing properties of the alloy.

The following Babbitt metal (plus aluminium) has been patented by Alexander W. Cadman (U. S. patent 464,147, December 1, 1891): Antimony 7.3 parts, tin 89, copper 3.7, with from ¼ to 2.5 parts aluminium.

Babbitt's anti-friction metal was formerly largely used, but is now in many cases replaced by other alloys.

Kingston's metal, formerly much used for bearings, is made by melting 9 parts of copper with 24 of tin, remelting, and adding 108 parts of tin, and finally 9 of mercury.

Anti-friction alloys for hydraulic machinery.—These alloys are recommended for hydraulic machinery, or where ordinary alloys are liable to be corroded by chemical solutions.

	Parts.		
	I.	II.	III.
Tin	16	16	—
Lead	3	—	16
Antimony	—	2	3
Cupro-manganese	3	2	3

Fenton's alloy for axle-boxes for locomotives and cars consists of zinc 80 parts, copper 5½ tin, 14½. This alloy may be recommended as regards cheapness and lightness. Experiments have shown that boxes of this alloy require but half as much oil for lubricating as others. The components can be melted in an ordinary iron pot, and the alloy is less difficult to work than brass.

Dewrance's patent bearing for locomotives consists of copper 4 parts, tin 6, antimony 8. A locomotive of the Liverpool-Manchester railroad ran over 4500 miles without the bearing requiring repair.

Alloy for anti-friction brasses.—Zinc 80 parts, tin 14, copper 5, nickel 1.

Alloy for metal stopcocks which deposits no verdigris.—Zinc 72 parts, tin 21, copper 7.

English white metal.—Tin 53 parts, lead 33, copper 2.4, zinc 1, antimony 10.6. The specific gravity of this alloy is 7.22 and it melts at 290° F.

A composition of white metal for machines recommended by Jacoby consists of copper 5 parts, tin 85, and antimony 10.

Hoyle's patent alloy for pivot bearings consists of tin 24 parts, lead 22, and antimony 6. It is claimed to stand friction without heating longer than any other composition.

In the factory of H. Roose, of Breslau, the following alloys are used for white metal bearings.

	Parts.			
	I.	II.	III.	IV.
Tin	18	18	—	—
Lead	3	—	8	8
Copper	1	1	1	—
Antimony	—	3	1	1

C. B. Dudley, during many years' experience in the laboratory of the Pennsylvania Railroad Company, has analyzed many bearing metals under various names. Some of these analyses are given as follows:*

Camelia metal.—Copper 70.20 per cent., tin 4.25, lead 14.75, zinc, 10.20, iron 0.55.

Anti-friction metal.—Tin 98.13, copper 1.60, iron, trace.

White metal.—Lead 87.92, antimony, by difference, 12.08.

Metal for lining car brasses.—Lead 84.87, antimony 15.10, tin, trace.

Salgee anti-friction metal.—Zinc 85.57, tin 9.91, copper 4.01, lead 1.15.

Graphite-bearing metal.—Lead 67.73, tin 14.38, antimony 16.73, iron not determined, graphite, none.

Carbon bronze.—Copper 75.47, tin 9.72, lead 14.57, carbon, possible trace.

Cornish bronze.—Copper 77.83, tin 9.60, lead 12.40, zinc, traces of iron, phosphorus.

Magnolia metal.—Lead 83.55, antimony, by difference, 16.45, traces of iron, copper, zinc, and possibly bismuth.

American anti-friction metal.—Lead 78.44, antimony 19.60, zinc 0.98, iron 0.65.

Tobin bronze.—Copper 59.00, zinc 38.40, tin 2.16, iron 0.11, lead 0.31.

Graney bronze.—Copper 75.80, lead 15.06, tin 9.20.

* Jour. Franklin Institute, February, 1892.

Damascus bronze.—Copper 76.41, tin 10.60, lead 12.52.

Manganese bronze.—Copper 90.52, tin 9.58, manganese, none.

Ajax metal.—Copper 87.24, tin 10.98, lead 7.27, phosphorus or arsenic 0.37.

Anti-friction metal.—Lead 88.32, antimony 11.93.

Harrington bronze.—Copper 55.73, zinc 42.67, tin 0.97, iron 0.68.

Car-box metal.—Lead 84.33, antimony 14.38, iron 0.61, zinc, trace.

Ex. B. metal.—Copper 76.80, tin 8.00, lead 15.00, phosphorus 0.20.

Dudley's investigations finally resulted in finding an alloy which wears 13 per cent. more slowly than phosphor bronze. This alloy consists of copper 76.80, tin 8.00, lead 15. To obtain uniform castings 0.20 per cent. phosphorus is added, the alloy being prepared according to the following formula: Copper 105 lbs., phosphor bronze, new or broken, 60 lbs., tin 9¾ lbs., lead 25¼ lbs.

The resulting alloy is the above-mentioned *Ex. B. metal* of the Pennsylvania Railroad Company.

The following tables of anti-friction metals which embrace most of the alloys of proved excellence has been selected and compiled by Mr. John F. Buchanan* from the best authorities and practice in the engineering world.

*Brassfounders' Alloys. London, 1905.

Anti-Friction Metals.

Parts.						
Copper.	Tin.	Zinc.	Lead.	Anti-mony.	Ferro-zinc.	
1	10	—	—	1	—	Babbitt's.
4	82	—	—	14	—	" No. 2.
1	6	—	—	2	—	" hardening.
1	6	—	—	2	—	" 10 % tin added.
4	6	—	—	8	—	Dewrance's.
5	16	79	—	—	—	Fenton's.
—	58½	39½	—	2	—	Parson's.
1	18	—	—	3	—	Roose's.
1	18	—	3	—	—	" No. 2.
—	46	—	42	12	—	Hoyle's.
4	19	69	5	3	—	Ledebur's.
7½	14½	78	—	—	—	Kingston's.
4	24	80	—	—	—	Calendonian.
4	18	90	—	—	—	" No. 2.
2	34	58	6	—	—	American Car Journals.
—	5	—	79	16	—	" " "
8	83	—	—	9	—	Tandem.
1	6	—	80	13	—	Magnolium.
1	3	—	80	16	—	"
4	88	—	—	8	—	American railway.
8	75	—	5	12	—	Plastic metal.
5	85	—	—	10	—	Admiralty metal.
5	82	—	—	13	—	" "
10	83	—	—	5	2	Plastic metal.
—	—	—	80	15	5	Anti-attrition metal.
—	5	—	76	16	3	" " No. 2.
1	94	—	—	5	—	Spinning metal.
3	90	—	—	7	—	" " No. 2.
2	67	30	—	1	—	White marine bronze.
2	42	56	—	—	—	" " " No. 2.
8	70	—	10	12	—	White navy bronze.

Anti-Friction Metals—Continued.

Parts.						
Copper.	Tin.	Zinc.	Lead.	Anti-mony.	Yellow metal.	
4	85	—	44	17	—	White navy bronze, No. 2.
14	60	26	—	—	—	White brass.
6	30	60	—	4	—	" " No. 2.
10	30	60	—	—	—	" " No. 3.
10	82	—	9	9	—	" " for patterns.
4	10	85	1	—	—	"Salgee" metal.
—	15	—	68	17	—	"Graphite" metal.
1	40	—	47	12	—	"Clyde" metal.
2	63	—	27	8	—	" " No. 2.
—	41	—	47	9	3	Barrow metal.
—	43	—	46	11	—	" " No. 2.
12	—	—	80	8	—	Metallic packing.
10	—	—	80	10	—	" "
—	10	—	70	20	—	" " French.
10	—	—	70	20	—	Eccentrics.
—	10	—	60	30	—	Piston rings.
—	30	—	60	10	—	" "
8	74	—	—	18	—	Hard plastic.
6	70	—	12	12	—	
—	76	—	7	17	—	
3	77	—	17	3	—	
—	38	—	38	24	—	Light machines.
5	40	—	45	10	—	Heavy machines.
8	82	—	—	10	—	Axle boxes.
6	82	—	—	12	—	Slide valves.
6	14	80	—	—	—	
—	—	47	47	6	—	
4	88	—	—	8	—	
—	53	—	33	10	4	

Anti-Friction Metals—Concluded.

Parts.								
Phosphor copper.	Copper.	Tin.	Zinc.	Lead.	Antimony.	Babbitt's Hardening.	Bismuth.	
12	—	55	—	33	—	—	—	Durable.
4	—	84	—	—	10	—	1	"Ideal."
—	—	17	—	58	—	25	—	
—	—	34	—	48	—	18	—	
—	—	37	—	34	—	19	—	
—	—	30	—	48	12	10	—	Fontainmoreau's bronze.
—	8	—	91	1	—	—	—	
—	—	18	75	4	3	—	—	Solid locomotive bearings.
—	6	17	77	—	—	—	—	
—	—	48	48	—	4	—	—	"Anchor Brand."
—	11	67	—	—	22	—	—	
—	5	35	60	—	—	—	—	
—	—	20	—	74	6	—	—	
—	1	92	—	—	7	—	—	"Titanium."
—	—	74	—	—	26	—	—	Hard face metre valves.
—	—	70	—	—	30	—	—	
—	1	68	31½	½	—	—	—	Very tough.

CHAPTER X.

NICKEL ALLOYS.

Although nickel in a pure state and as a distinct metal has been known only for a comparatively short time, in many localities it has for many years been indirectly used in the preparation of alloys. As far back as the seventeenth century, alloys were brought to Europe from China which were distinguished by quite a white color and considerable hardness, and were known by various names. The actual Chinese name packfong—or packtong—of this alloy means white copper. Engström, in 1776, found it to consist of copper 40.5, zinc 44.3, and nickel 15.2, while the analysis of a specimen by Fyfe, in 1822, gave copper 41.0, zinc 2.65, nickel 8 and iron 2.7. The alloy is probably prepared by the Chinese in a manner similar to that in which brass was made in Europe before zinc in a metallic state was known, namely, by fusing copper with nickeliferous minerals.

As far back as 1770, a similar white alloy, known as Suhl white copper, was prepared in Europe from white metallic grains obtained by crushing and washing old slag. According to Brandes (1823) these grains consisted of copper 88, nickel 8.75, iron, silica and alumina 1.75, and antimony and sulphur 0.75. By adding zinc and tin an alloy was obtained which was used for spurs and gun-mountings, and contained, according to Keferstein, copper 40.4, zinc 25.4, nickel 31.6, and tin 2.6. According to Frick, the alloy, whose content of nickel and the white color dependent thereon was established in 1823, contained copper 11 parts, zinc 7¾, and nickel 1. In 1823, the society for promoting industry in Prussia offered a prize for the invention of an alloy which, while similar in appearance to silver, should

cost no more than $\frac{1}{6}$ the price of the latter, and be suitable for culinary and table purposes. In 1824, such an alloy was prepared almost simultaneously by Henniger Bros. of Berlin, and Dr. Geitner, of Schneeberg. The latter called his alloy *argentan*, and prepared it at first from cobalt speiss (on an average with 49 nickel, 37 arsenic, 7 sulphur, besides iron and other metals), the result being that the composition of the alloy was not always constant. Henniger Bros. called their alloy "Neusilber" (new silver). Later on the alloy was prepared only from copper, zinc and metallic nickel, and it was soon introduced in France under the names of *Maillechort* (called thus after the first manufacturers, Maillet and Chorier), *argent d' Allemagne*, *argent allemand*, *argent neuf*, and in England under the name *German silver*.

In Vienna the alloy has been prepared since 1824, and was called *alpaka*, in Paris, *alfenide*, while the Chinese name packfong has been retained for inferior qualities poorer in nickel and containing other metals. Articles quite heavily silver-plated were introduced in 1840, and are knows as *China silver or Christophle metal.*

According to other statements the above-mentioned alloy, known as Maillechort, contains at the utmost 15 per cent. nickel; and alloys which besides copper, zinc and nickel, contain other metals (tin, bismuth, antimony) to obtain greater fusibility and a more beautiful color, are known as *silverine*, *argentan. packfong*, etc.

Nickel-copper alloys.—Nickel and copper unite in a wide range of proportions, the color of the alloys varying from copper-red to the blue-white of the nickel, according to the proportions of the respective metals. With a content of 0.10 per cent. nickel the alloy is very ductile, of a light copper-red color, and moderate strength; with 0.15 per cent., the ductility is still considerable, while the color changes to a very pale red; a content of 0.25 per cent. of nickel gives a nearly white alloy, and 0.30 per cent., a

silver-white metal. The beautiful white color and considerable hardness imparted to copper by an addition of nickel make the alloy especially suitable for coinage, and it is used for this purpose in Switzerland, Belgium, and the United States. Both the Belgian and the United States coins now contain copper 75, nickel 25. The modern small coins of Switzerland, France, Sweden, Denmark, England and Belgium, contain a small addition of tin and zinc, and those of Italy only of tin. Chilian coins are composed, since 1872, of copper 70, nickel 20, zinc 10.

The use of alloys consisting of copper and nickel alone is limited, those consisting of copper, nickel and zinc being more frequently employed. C. Morfit prepares a beautiful alloy of nickel and copper by mixing 33 parts of nickel and 34 parts of copper with some borax, and fusing in a graphite crucible. To the melted mass he adds, with constant stirring, 33 parts more of copper, and casts the resulting alloy in small sticks.

Berthier's alloy consists of copper 0.682 parts, nickel 0.318. It is fusible, ductile, strong, bluish-white, slightly magnetic, and somewhat crystalline near the surface.

Ingot-iron sheet, plated on both sides with an alloy of copper 80 and nickel 20, serves for the manufacture of cartridge shells.

According to Vivian,* copper sheet with 1 to 3 per cent. nickel can be rolled hot and is stronger and tougher than sheet of copper or brass. An alloy with 50 to 60 per cent. nickel is used in watch factories, but otherwise serves only as a raw material for other alloys.†

Künzel and Montefiore-Levi endeavored in vain to produce a nickel-copper alloy not subject to liquation, and which, with the same or greater degree of hardness, would possess greater elasticity, more absolute strength and toughness than ordinary gun-metal. With a content of up

*English Patent No. 13358, Sept. 15, 1888.

†German patent No. 24188.

to 10 per cent. nickel and 90 per cent. copper, these alloys did not possess the required hardness, while with over 10 per cent. nickel the castings obtained were porous, because such combinations richer in nickel absorb in fusing large quantities of oxygen which becomes free in cooling. This is also the reason for the difficulty encountered in making nickel coins of copper 75, nickel 25, the alloy adopted by Belgium, Germany and the United States. By an addition of aluminium or phosphor-copper, dense castings may be obtained in iron moulds. While large cavities formed in consequence of too high a temperature in casting or incorrect cooling generally yield useless castings, smaller cavities distributed throughout the entire mass disappear by rolling and stamping, and are of no disadvantage.

Nickel-copper-zinc alloys.—These alloys form the mixtures of metals known as German silver, packfong, *argent neuf*, etc. They may in a measure be considered as a brass, which, by an addition of nickel, has acquired a white color and considerable hardness.

Generally speaking, German silver is superior to brass as regards hardness, strength and power of resisting chemical influences, the latter property making it especially valuable for certain purposes. In respect to its preparation it is, however, a very subtle mixture, and exceedingly small quantities of foreign metals exert a considerable influence upon the physical properties of the alloy.

A content of arsenic is most injurious in this respect. Even a very small percentage of it renders the alloy so brittle that it can scarcely be worked, and in a short time changes its color to brownish.

A considerable portion of nickel is obtained from an ore known as copper-nickel or arsenical nickel, and from certain cobalt ores. Both ores, however, always contain considerable quantities of arsenic, which it is impossible to remove entirely by the ordinary mode of smelting. This content of arsenic prevented for a long time the general introduc-

tion of nickel alloys in practice, and it became necessary entirely to abandon the method of preparing nickel by the dry method. It is now prepared by the wet method, in order to obtain protoxide of nickel entirely free from arsenic. This protoxide is then made into small cubes with starch-paste and heated at a very high temperature. By this treatment it is reduced to metal, the pure nickel remaining behind in the form of a quite dense metallic sponge, which is, however, not fused, but simply slagged, nickel belonging to the metals very difficult to fuse. It may here be mentioned that for making alloys, it is really better to have the nickel, not as a compact fused mass, but in the form of a sponge, the latter combining with greater ease with the other metals.

Nickel ores are also reduced by fluxing with chalk and fluorspar, if arseniated, or by roasting, and then reducing with charcoal and sulphur to the state of sulphide. By double decomposition with carbonate of soda the carbonate is then obtained, which is finally reduced with charcoal.

Nickel and cobalt are closely allied as regards chemical properties and frequently occur together, so that the nickel found in commerce often contains a considerable quantity of cobalt, which passes into the alloy without, however, exerting an injurious influence. The same may be said of iron, also chemically closely allied to nickel, a content of it even increasing the tenacity and hardness of the nickel alloys and imparting to them a whiter color. But, on the other hand, it makes them more difficult to work, and renders them somewhat brittle. The genuine packfong, the original nickel alloy introduced from China, contains sometimes as much as three per cent. of iron. European manufacturers also frequently add a small quantity of iron to German silver, if a high degree of hardness is required for certain purposes.

Some skill is, however, required to effect an actual combination of the alloy with the iron. By adding the iron

directly to the fused alloy it does not combine with it, and forms upon the surface of the fused mass a layer consisting of copper, nickel, and the added iron. An alloy of iron and copper dissolves, however, readily in the German silver, and an intimate union of all the metals can be easily effected by melting together equal portions of copper and steel, and adding pieces of this alloy to the fused German silver.

An addition of silver to German silver does not affect its properties injuriously, nor an addition of a few per cent. of lead, which makes the alloy more fusible, somewhat cheaper, and improves its color. It is, however, remarkable that only a very small addition of lead renders the alloy quite brittle.

By an addition of tin, German silver acquires considerable hardness and a beautiful sound. An alloy of this kind containing a suitable quantity of tin could be used as speculum-metal and bell-metal. But the previously given compositions for these purposes being very suitable and much cheaper, tin alloys containing nickel are not used in practice.

As regards the properties of nickel alloys they may be summed up as follows: The color of the mixture is always white, the degree of whiteness depending on the quantity of the separate metals used in the respective composition. The most beautiful color is shown by an alloy of 4 parts of copper and 3 of nickel, but unfortunately this alloy is scarcely available for practical purposes, it being extremely difficult to fuse, and so hard that it can scarcely be worked. An alloy containing 75 parts of copper and 25 of nickel does no longer show a pure white color, but one with a yellowish tinge, which is clearly perceptible by holding a polished piece of such an alloy alongside a piece of silver. Hence the better qualities of German silver must in all cases contain more than one-fourth of nickel. In using a small quantity of nickel it has been attempted to remove the yellowish color by an addition of silver; but without success. The Swiss coins are made of such an alloy, and, as is well known, show a decidedly yellowish cast.

In most factories the articles made of German silver are plated with silver by the electric current, and exhibit the color of chemically pure silver, which they retain for a shorter or longer time according to the thickness of the deposit.

The mechanical manipulation of German silver is attended with some difficulties, the plates, which for the purpose of preparing sheet must be obtained by casting, being highly crystalline and readily cracking under the hammer.

Generally small plates about 7¾ to 12 inches long, 4¾ to 7¾ inches wide, and ⅓ inch thick are prepared by casting. These plates are slightly rolled and hammered, being annealed after each mechanical manipulation. By this treatment they gradually lose the crystalline structure, and when this has entirely disappeared, can be further worked with ease, and rolled and stamped into any desired form, most articles (spoons, forks, etc.) being prepared by the latter method. Like alloys of the precious metals, German silver has the property of retaining its metallic color and luster on being brought in contact with air and water, and it is not effected even by dilute acids such as are frequently found in food (lactic acid, acetic acid, etc.).

Nickel alloys possessing strong electric properties are used in the manufacture of positive elements for thermo-electric piles, they being especially adapted for the purpose on account of their high melting points. A thermo-electric pile, one portion of which consists of a nickel alloy, can be heated to a strong red heat without fear of the alloy melting.

German Silver or Argentan.

Alloys of nickel, copper and zinc are recognized in commerce under all sorts of names, but in order to avoid confusion we will retain the term German silver or argentan, which is most in use. Factories which produce this alloy are found in almost all large cities, though Germany and England are the chief seats of the industry. The composi-

tion of the alloys used by the various factories differs considerably, as may be seen from the following figures:—

Copper	50 to 66 parts.
Zinc	19 to 31 parts.
Nickel	13 to 18 parts.

For the production of spoons, forks, cups, candlesticks, etc., alloys consisting of copper 50 parts, nickel 25 and zinc 25 are most suitable, as they show a beautiful white-blue color which does not tarnish.

German silver is sometimes so brittle that a spoon allowed to fall upon the floor will break, this fragility being due, of course, to an incorrect composition. It is impossible to give a definite composition for German silver, inasmuch as it varies according to the manipulation the article manufactured from the alloy is to undergo. The following table of analyses of different kinds of German silver shows how the qualities of the alloys change with the percentage of metals contained in them. Immaterial admixtures of foreign metals have been omitted in the compilation, only those belonging to the composition of the alloy being given:

German silver.	Parts.			Quality.
	Copper.	Zinc.	Nickel.	
English	8	3.5	4	Finest quality.
"	8	3.5	6	Very beautiful, but very refractory.
"	8	6.5	3	Ordinary, readily fusible.
German	52	26	22	Prime quality.
"	59	30	11	Second quality.
"	63	31	6	Third quality.

The following analyses give interesting particulars concerning various kinds of alloys for German silver:

German silver.	Parts.				
	Copper.	Zinc.	Nickel.	Lead.	Iron.
French for sheet	50	31.3	18.7	—	—
	50	30	20	—	—
	58.3	25	16.7	—	—
Vienna	50	25	25	—	—
	55.6	22	22	—	—
	60	20	20	—	—
Berlin	54	28	18	—	—
	55.5	29.1	17.5	—	—
English	63.34	17.01	19.13	—	—
	62.40	22.15	15.05	—	—
	62.63	26.05	10.85	—	—
	57.40	25	13	—	3.00
Chinese	26.3	36.8	36.8	—	—
	43.8	40.6	15.6	—	—
	45.7	36.9	17.9	—	—
	40.4	25.4	31.6	—	2.60
For casting	48.5	24.3	24.3	2.9	—
	54.5	21.8	21.8	1.9	—
	58.3	19.4	19.4	2.9	—
	57.8	27.1	14.3	0.8	—
	57.0	20.0	20.0	3.0	—
Sheffield—					
Common (yellow)	59.30	25.90	14.80	—	—
Silver-white	55.20	24.10	20.70	—	—
Electrum (bluish)	51.60	22.60	25.80	—	—
Hard (can be worked cold)	45.70	20.00	31.30	—	—
Fricke's—					
Bluish-yellow (hard)	55.50	39.00	5.50	—	—
Pale yellow (ductile)	62.50	31.20	6.30	—	—
Silvery (hard)	50.00	18.80	31.20	—	—
" (harder)	59.00	30.00	10.00	—	—
Common formula	55.00	25.00	20.00	—	—

Many varieties of German silver contain different quantities of iron, manganese, tin, or very frequently lead, to change the qualities of the alloy or to cheapen it. All these additions, however, exert rather an injurious than beneficial influence, and especially lessen the power of resistance against the action of dilute acids, which is one of the most valuable properties of this alloy.

An addition of lead makes German silver more fusible; one of tin acts in a certain sense as in bronze, making the alloy denser and more sonorous, and causing it to take a

better polish. An addition of iron or manganese increases the white color of the alloy, but it becomes at the same time more refractory and inclines towards brittleness.

Substitutes for German Silver.—There are a number of directions for the preparation of alloys to be used as substitutes for German silver, but none of them has succeeded in entirely replacing the latter, a proof that it possesses advantages not belonging to the others.

Nickel-bronze.—This alloy is prepared by fusing highly purified (99.5 per cent.) nickel with copper, tin and zinc, so that the resulting bronze contains 20 per cent. nickel. It is of a light color and possesses great strength.

According to Garnier, nickel containing phosphorus alloyed with copper, zinc, and iron gave better results than such alloys without copper.

Bismuth-bronze.—Webster's bismuth-bronze is made in various proportions. According to the statement of its discoverer its composition and qualities are as follows: For a hard alloy take 1 part of bismuth and 16 of tin, both by weight, and, having melted them, mix them thoroughly. For a hard bismuth-bronze take 69 parts of copper, 21 of spelter, 9 of nickel, and 1 of the above hard alloy of bismuth and tin. This bismuth-bronze is a hard, tough, sonorous, metallic alloy, which is proposed for use in the manufacture of screw-propeller blades, shafts, tubes and other appliances employed partially or constantly in sea-water. In consequence of its toughness it is thought to be well suited for telegraph wires and similar purposes where much stress is borne by the wires. From its sonorous quality it is well adapted for piano wires. For domestic utensils and articles exposed to atmospheric influences, use bismuth 1 part, aluminium 1, and tin 15, melted together to form the separate or preliminary alloy, which is added in the proportion of 1 per cent. to the above-described alloy of copper, spelter, and nickel. This bronze forms a bright and hard alloy suited for the manufacture of utensils or articles exposed to oxidation.

Manganese German Silver.—As a substitute for German silver, Boucelin and Ponsard recommend an alloy of copper 60, zinc 15 and ferro-manganese with 70 to 80 per cent. manganese, 40. For bearings, cocks and valves: Copper 60, zinc 10 and ferro-manganese with 60 per cent. manganese, 40. According to Ledebur, the collection of the Freiberg School of Mines contains a moderately ductile sheet of a pale yellow color composed of copper 60.95, manganese 7.95, zinc 29.93 and iron 1.13, and another sheet of a paler, but still perceptible yellow color, composed of copper 63.16, manganese 4.48, zinc 26.11, iron 0.74, and nickel 3.67.

The following composition is recommended as being readily cast, and hence very suitable for articles of art.

Copper	52 to 50
Nickel	17 to 15
Zinc	5 to 10
Manganese	1 to 5
Phosphorus	— —
Copper with 15 per cent. phosphorus	3 to 5

Aphtit.—The alloy known by this name is composed of: Iron 66, nickel 23, tungsten 4, copper 5.

Arguzoid.—Copper 55.78, zinc 23.198, nickel 13.046, tin 4.035, lead 3.544. This alloy is silver-white, almost ductile, and suitable for articles of art.

Ferro-German silver prepared by the *Société anonyme Le Ferro-Nickel* of Paris consists of iron, nickel and copper with or without zinc.

A silver-like alloy, which can be worked like German silver, is composed of copper, 70; nickel, 20; zinc, 5½; cadmium, 4½.

Platinoid.—This alloy, invented by H. Martino, is a kind of German silver with an addition of 1 to 2 per cent. of tungsten. The latter, in the form of phosphor-tungsten, is first melted together with a certain quantity of copper, the nickel is next added, then the zinc, and finally the remainder

of the copper. In order to remove the phosphorus and a portion of the tungsten, both of which separate as dross, the resulting compound is several times remelted. Finally an alloy of a beautiful white color is obtained, which, when polished, closely resembles silver, and retains its luster for a long time. Platinoid has the properties of German silver in a pre-eminent degree. It shows great resistance, which changes but little with the temperature, and is about 1½ times greater than that of German silver. To determine the dependence of the resistance on the temperature, platinoid wire was wound upon a bobbin provided with a thread, and uniformly heated in an oil-bath. The results of the experiments are given in the following table, in which the resistance at 0° C. is placed = 1.

Temperature.	Resistance.	Temperature.	Resistance.
0° C.	1.0000	60° C.	1.0126
10	1.0024	70	1.0134
20	1.0044	80	1.0166
30	1.0066	90	1.0188
40	1.0075	100	1.0209
50	1.0097		

This shows an average increase of resistance of 0.0209 for 1° C. between 0° and 100° C.; another experiment with wire gave an average of 0.022 for 1° C. According to experiments by Matthiessen, and the more recent ones, by Erno, the increase in the resistance of copper is 0.38 per cent., and of German silver 0.044 per cent. Hence platinoid is in this respect far superior to other wire in use.

Manganin. Copper, 83; nickel, 4; manganese, 13.

Dienett's German silver. This alloy is said to possess a beautiful white color and the density and toughness of tombac. It is composed of copper, 4, zinc, 2.5, lead, 0.75, nickel, 0.5 and tin, 0.125.

Pirsch's patented German silver is composed of

Copper.	Nickel.	Cobalt.	Zinc.	Anti-mony.	Alumin-ium.	Iron.
79.50	16.00	1.00	1.00	1.00	0.50	1.00
75.00	16.00	2.00	2.25	2.75	0.50	1.50
71.00	16.50	1.25	7.50	2.50	—	1.25

Alfénide, Argiroide, and allied alloys. — The alloys brought into commerce under these and many other names consist in most cases of a mixture of metals closely resembling German silver, but they are always electro-plated with pure silver, the thickness of the plating depending on the price of the respective articles. In many cases the composition used in the manufacture of these articles is a very ordinary quality of German silver, which by itself would present a mean appearance, but is hid from the buyer by the silver plating.

In recent times alloys have been frequently recommended which differ from the actual nickel alloys as represented by German silver, in containing tin and aluminium, which makes them more fusible and more easily worked than German silver. Thus far these alloys have not been generally introduced in practice, and besides they are dearer than German silver.

According to Rochet, alfénide is composed of 59.1 parts of copper, 30.2 of zinc, 9.7 of nickel, and 1.0 of iron. According to this, it is actually nothing but an ordinary quality of German silver. It is said to be well adapted for spoons, forks, and other articles with a smooth surface which are to be plated with silver, but it does not answer so well for decorated pieces.

Toucas's alloy is composed of copper 5 parts, nickel 4, antimony, tin, lead, zinc, and iron, of each 1. The metals are melted together in a crucible. This alloy has the advantage of being more complex, even if it does not possess other qualities, than similar compounds. According to the inventor, it has nearly the color of silver, may be worked like

it, and is laminated by the ordinary processes. It is resisting, malleable, suspectible of a fine polish, with a luster of platinum, and can be perfectly silvered. For objects which are to be spun, hammered, or chased, the above alloy is very convenient, but for cast and adjusted pieces it is preferable to increase the proportion of zinc in order to increase the fluidity of the metal. This compound is employed for ornaments, jewelry, etc.

According to Trabuk, of Nimes, a beautiful white alloy, which resists the action of vegetable acids, and may serve as a substitute for German silver, is obtained by melting together 875 parts of tin, 55 of nickel, 50 of antimony, and 20 of bismuth. Into a crucible of suitable size introduce first ⅓ of the tin and all the nickel, antimony and bismuth, and after covering these metals with the second third of tin, cover the whole with a layer of charcoal powder to prevent oxidation. The lid is then placed upon the crucible and the latter heated to a bright red heat. After ascertaining by stirring with a red-hot iron rod that all the nickel is fused, the last third of the tin is added, without, however, removing the layer of charcoal. The mass is then stirred until it is perfectly homogeneous, and cast into ingots.

The annexed table gives a number of nickel alloys arranged according to their composition:

Analyses of Nickel Alloys.

	Copper.	Zinc.	Nickel.	Lead.	Iron.	Tin.	Silver.	Cobalt.
I. *Copper, zinc and nickel.*								
French Maillechort, according to Levoir.	65	20	15	—	—	—	—	—
French Maillechort, according to Levoir.	60	20	20	—	—	—	—	—
French Maillechort, according to Levoir.	60	15	25	—	—	—	—	—
French Maillechort, according to Levoir.	55	15	30	—	—	—	—	—
French German silver, according to d'Arcet	50	30	20	—	—	—	—	—
French German silver, according to Chaval	58.3	25	16.7	—	—	—	—	—
Birmingham German silver for table ware	62.40	22.15	15.05	—	—	—	—	—
Sheffield German silver, very elastic	57.40	25.00	13.00	—	3	—	—	—
Vienna German silver:								
Copper 2, zinc 1, nickel 1, for forks and spoons, not very white, but hard and does not tarnish	50	25	25	—	—	—	—	—
Copper 5, zinc 2, nickel 2, for forks and knives; resembles silver 0.750 fine	55.6	22.2	22.2	—	—	—	—	—
Copper 3, zinc 1, nickel 1, resembles silver 0.750 fine; readily rolled and worked	60	20	20	—	—	—	—	—
Spoon metal, according to Schubarth	50.00	31.25	18.75	—	—	—	—	—
English Packfong, according to Engström	40.6	43.7	15.6	—	—	—	—	—
German German silver, according to Bolley	54.0	28.0	18.0	—	—	—	—	—
German German silver, according to Frick	55.5	29.1	17.5	—	—	—	—	—

Analyses of Nickel Alloys—Continued.

	Copper.	Zinc.	Nickel.	Lead.	Iron.	Tin.	Silver.	Cobalt.
Alfénide, according to Bolley	59	30	10	—	—	—	—	—
Chinese German silver, very ductile and softer than German	26.3	36.8	36.8	—	—	—	—	—
Chinese tutenag for casting, very fusible, of a beautiful white color, but hard, and difficult to roll	45.7	36.9	17.4	—	—	—	—	—
Markus's alloy for thermo-piles	10	6	6	—	—	—	—	—
II. *Copper, zinc, nickel, lead.*								
For castings, copper 2, zinc 1, nickel 1, lead 0.12	48.5	24.3	24.3	2.9	—	—	—	—
For castings, copper 5, zinc 2, nickel 2, lead 0.18	54.5	21.8	21.8	1.9	—	—	—	—
For castings, copper 60, zinc 20, nickel 20, lead 3	58.3	19.4	19.4	2.9	—	—	—	—
Closely resembling silver	57.8	27.1	14.3	0.8	—	—	—	—
For articles to be soldered, according to Gersdorff	57	20	20	3	—	—	—	—
Paris white metal for spoons, forks, etc.	69.8	5.5	19.8	—	—	—	—	—
Paris yellow metal	79.7	0.28	13.05	—	—	0.09	—	—
III. *Copper, zinc, nickel, iron.*								
English German silver, very elastic, according to Elsner	57.4	25.0	13.0	—	3.0	—	—	—
Paris Maillechort, according to Henry	65.4	13.4	16.8	—	3.4	—	—	—
Alfénide for tableware, according to Rochet	59.1	30.2	9.7	—	1.0	—	—	—
Chinese packfong, best quality, according to Fyfe	40.4	25.1	31.6	—	2.6	—	—	—

Analyses of Nickel-Alloys—Continued.

	Copper.	Zinc.	Nickel.	Lead.	Iron.	Tin.	Silver.	Cobalt.
For articles to be soldered, white, hard, brittle	53	23	22	—	2	—	—	—
Metal for beer-glass lids	59.23	23.31	16.27	0.28	0.28	0.12	0.02 Sb	0.42
IV. *Copper, tin, nickel, with or without zinc.*								
Keene's silver-like alloy	75	2.25	16	—	1.50	2.75	0.50 Al	2
Very suitable for castings, copper 30, tin 17, nickel 10	52.5	—	17.7	—	—	28.8	—	—
For bells and bearings, according to Elsner; steel-like with a reddish tinge, capable of taking a high polish, very hard, slightly ductile, of a beautiful sound, not attacked by sulphuretted hydrogen	50	—	25	—	—	25	—	—
For mirrors and reflectors, copper 32, tin 15½, nickel 2	64.6	—	4.1	—	—	31.3	—	—
For bearings, almost indestructible, according to Winckler	50	—	25	—	—	25	—	—
Suhl white copper	40.4	25.4	31.6	—	—	2.6	—	—
V. *Copper, nickel, silver* (Ruolz alloys).								
For rolling, pressing and drawing	37 to 42	—	25 to 30	—	—	—	38	—
For jewelry	30 to 40	—	20 to 30	—	—	—	40	—
For casting	45 to 55	—	25 to 35	—	—	—	20	—
For rolling, pressing and drawing	41.8	16.3	8.6	—	—	—	33.3	—
For jewelry	44.6	10.8	4.6	—	—	—	40	—

Analyses of Nickel-Alloys—Concluded.

	Copper.	Zinc.	Nickel.	Lead.	Iron.	Tin.	Silver.	Cobalt.
Silver-like alloy, according to Pirsch-Baudoin	71	7	16.5	—	1.25	2.5	—	1.75
Lutecin or Paris metal of LeMat	80	5	16	—	5	2	—	1
VI. *Other alloys.*								
German silver from Sheffield, copper 60, nickel 20, zinc 20, iron 2, lead 3, very white and brittle	57.1	19.0	19.0	1.9	3	—	—	—
English German silver, somewhat more yellow than German	60	17.8	18.8	—	—	—	—	3.4
American German silver, copper 96, zinc 36, nickel 24, cobalt 1, iron 1, tin 2, silver 2, manganese 2	58	21.7	14.5	2.4 Mn	0.6	1.2	1.2	0.6
Silverine	71 to 79.5	1 to 7.5	16 to 16.5	—	1 to 1.5	1 to 2.75	Alo to 0.5	1 to 2
Parker's chromium alloy	60	20	10	10 Cr	—	—	—	—
Toucas's German silver	35.7	7.1	28.6	7.1	7.2	7.2	Sb 7.1	—
China silver, according to Meurer	65.24	19.52	13.0	—	trace	As 2	—	—
Chinese white copper, according to Levol	79.40	—	16.2	—	4.58	—	—	—
Minargent	100	—	70	Sb 50	—	—	—	—

Sperry* gives the following analyses of nickel alloys.

	Per cent.				
	Copper.	Nickel.	Zinc.	Iron.	Cobalt.
Berlin alloys:					
Richest	52.00	22.00	26.00	—	—
Medium	59.00	11.00	30.00	—	—
Poorest	63.00	6.00	31.00	—	—
French alloys:					
Tableware	50.00	18.70	31.30	—	—
"	50.00	20.00	30.00	—	—
Maillechort	65.40	16.80	13.40	3.40	—
Copper-nickel alloy of the Soc. de Nickel, Paris	48.74	49.26	S 0.089	0.610	Si 0.186
Copper-nickel of Wiggins & Co., Birmingham	47.68	49.87	S 0.041	1.228	Si 0.136
Christofle's alloy	50.00	50.00	—	—	—
Austrian alloys:					
Tableware	50.00	25.00	25.00	—	—
"	55.60	22.20	22.20	—	—
"	60.00	20.00	20.00	—	—
Sheffield, England, alloys:					
White silver	55.20	20.70	24.10	—	—
Electrum	51.60	25.80	22.60	—	—
Hard alloy	45.70	31.30	20.00	—	—
English	60.00	18.80	17.38	—	3.40
" elastic	57.00	15.00	25.00	—	3.00
Chinese packfong	40.40	31.60	25.40	2.00	—
Vivian's copper alloy	48.49	50.09	—	0.826	Si 0.303
American alloys:					
Alloy for casting	52.50	17.70	28.80	—	—
Bearing alloy	50.00	25.00	25.00	—	—
Explosive bullet-shell	75.50	24 10	—	0.40	—

Manufacture of German Silver on a Large Scale.

In the manufacture of German silver, the purity of the metal used is of greater importance than in the preparation of any of the alloys previously described. The nickel found at present in commerce is generally sufficiently pure to be used without further preparation, the chief contamination

*Transactions of the American Institute of Mining Engineers, Florida Meeting, March, 1895.

being cobalt, which, as previously mentioned, exerts little influence upon the properties of the alloy. Copper is frequently contaminated with iron, lead, arsenic, and antimony, and, in such case, is only fit for the preparation of German silver of second or third quality. Zinc also contains certain contaminations injurious to the qualities of the alloy.

The manufacture of German silver is generally carried on according to two methods which, from the countries where they have been perfected, are termed respectively the *English* and the *German* process. Both yield German silver of excellent quality, and, as will be seen from the descriptions of the two methods, differ chiefly in the manner in which the various operations in melting down the alloys are executed.

German process.—The alloy is prepared as follows: The zinc and nickel to be used for a certain quantity of copper are divided into three equal portions. Now place upon the bottom of a graphite crucible, capable of holding at the utmost 22 pounds of the alloy, a layer of copper, upon this a layer of zinc and nickel, upon this again a layer of copper, and continue in this manner until all the copper is in the crucible, retaining, however, one-third each of the nickel, and zinc.

The contents of the crucible are now covered with a layer of charcoal powder to prevent volatilization and oxidation of zinc, and melted down as quickly as possible in a wind-furnace connected with a high chimney, quite a high temperature being required for the fusion of the alloy.

When the contents of the crucible are supposed to be liquefied, they are examined by dipping in an iron rod, and, if the whole is found to be thoroughly melted, an intimate mixture of the metals is effected by vigorous stirring with the rod.

The zinc and nickel retained are now added in portions to the melted contents of the crucible, the mass being vigor-

ously stirred after each addition, and a sharp fire kept up to prevent the alloy from cooling off too much by the newly-introduced metals. After the introduction of the last portion, an additional piece of zinc is generally thrown into the crucible to compensate for the loss of zinc by volatilization, and besides experience has shown that a small excess of zinc renders the alloy more thinly-fluid, which materially facilitates the work in the subsequent casting. If the alloy is to be rolled out into thin sheets, it is recommended to keep the finished alloy liquid for some time longer before proceeding to casting. In doing this, however, it is necessary constantly to keep the surface of the melted metal covered with charcoal to prevent volatilization of zinc.

The casting of the alloy is effected in various ways. It is either at once cast into plates, which are subsequently rolled out into sheets, or into very thin sticks, which after cooling are remelted and finally cast into plates. On account of the greater consumption of fuel and labor, the last method is somewhat more expensive than direct casting, but it has the advantage of the alloy becoming more homogeneous by remelting, and besides it can be worked with greater ease. Only with the use of very pure metals is it advisable to cast the alloy at once into plates.

Considerable skill is required for casting the alloy, it being necessary to run it into the moulds at as high a temperature as possible and in an uninterrupted stream. An interruption of the stream can be at once detected by the fact that the plate is not uniform.

The moulds used in casting plates consist of two iron plates, one plain and the other with a ledge corresponding to the thickness of the plate to be cast, which varies from 0.50 to 0.59 inch. On account of the great contraction of the alloy in solidifying, the distance between the two plates must be somewhat greater. In order to obtain castings of greater homogeneousness, it is recommended to run the melted metals from below into the moulds. This is effected

by providing the lower plate with a lip or mouth-piece, in which is placed a clay-funnel connected with a pipe rising somewhat above the mould. After the plates are tightly screwed together, the mould is highly heated and the casting proceeded with. The metal is heated as intensely as possible, and after being freed from all contaminations floating on the surface is allowed to run in a steady, thin stream into the mould. When the metal appears on the upper end of the mould and the funnel remains filled, the casting is finished. After allowing the filled mould to stand quietly for about half an hour, the solidified plate is removed. To prevent the alloy from adhering to the sides of the mould, these are previously to casting coated with a layer of fine lamp-black. The principal difficulty in casting plates of German silver is to obtain them perfectly homogeneous and free from blow-holes, which is best effected by bringing the melted metal as hot as possible into the mould. On account of the difficulty of executing the casting so quickly that the contents of the crucible do not cool off, it is recommended to fill only one mould at a time, and replace the crucible in the furnace in order to keep the contents at the highest temperature possible.

The plates of German silver thus obtained have to be carefully examined as to whether they are perfectly homogeneous. Imperfect plates must be thrown out and remelted. The perfect plates are rolled out into sheets from which the articles to be manufactured are punched out and then further worked.

English process.—The English method of preparing the alloy differs somewhat from the German, especially in the manner in which the metals are melted together, no portion of the zinc or nickel being retained, but the entire quantity of metal is melted at one time. Good graphite crucibles are used, which are placed in a furnace capable of producing a high temperature. The metals are used in the form of small pieces. The charge of each crucible generally con-

sists of 8¼ pounds of tin, ½ pound of zinc, and, according to the quality of the alloy to be produced, 2 to 3 pounds of nickel. The metals are intimately mixed and quickly introduced into the red-hot crucibles. Their surface is immediately covered with a thick layer of coal-dust and the mixture fused as quickly as possible. After ascertaining by stirring with an iron rod that the mass is liquefied, a previously prepared alloy of 1 part by weight of zinc and ½ part of copper is added, the quantity for the above charge ranging from 1⅗ and 2 pounds. When this alloy is melted and the entire contents of the crucible form a homogeneous whole, 2 pounds of zinc are finally added. The mass, being kept constantly covered with coal-dust, is now heated as strongly as possible, and when thinly-fluid a sample is taken to test its qualities.

The alloy always contains a certain amount of oxide, and, if a large quantity of it is present, the casting will be badly blown. To ascertain how the alloy will act in casting, a test casting is made, and, if the fracture of this shows blow-holes, the oxides will have to be reduced. This is effected by throwing pitch into a stoneware pipe pushed through the contents of the crucible to the bottom. The products of destructive distillation evolved from the pitch effect a reduction of the oxides, which is accelerated by stirring coal-dust into the melted metal. When the reduction of oxides is supposed to be finished, a strong heat is given, and, after the coal mechanically mixed with the alloy has collected upon the surface, the purified metal is cast in a manner similar to that described under the German process. Instead of coating the moulds with lamp-black alone, many manufacturers use a mixture of lamp-black and oil of turpentine. Moulds thus treated must, however, be sharply dried to volatilize the oil of turpentine, as otherwise the vapors evolved from the oil of turpentine in casting might readily cause the formation of blow-holes.

The casting of the plates finishes the chemical portion

of the process, and the perfect plates are mechanically worked in the same manner as indicated under the German process. Articles of German silver have to be soldered with a solder whose color approaches as nearly as possible that of the alloy. An excellent composition for this purpose is prepared by melting 5 to 6 parts of German silver together with 4 parts of zinc. It is, however, better directly to prepare the alloy which is to serve as solder by melting together copper 35 parts, zinc 57, and nickel 8.

The alloy is prepared in the same manner as German silver and, after being cast in thin plates, pulverized while hot. If the alloy is too tough and can only be pulverized with difficulty, it contains too little zinc, while too great brittleness indicates too small a quantity of nickel. In both cases the alloy must be improved by remelting and adding the necessary quantity of the respective metals.

The alloys of German silver are principally used for the manufacture of tableware, as cups, dishes, forks, spoons, etc., but on account of their beautiful color, and solidity, they are also used for articles of art, and are more and more substituted for genuine silver. For fine mechanical work German silver surpasses all other alloys, it having, besides considerable strength and power of resistance, the valuable property of not changing its appearance in contact with dry air, and of expanding but little on heating.

Manufacture of German silver sheet. The crystalline plates obtained by casting are very gradually reduced by rolling. Whilst being passed through the rolls, they are repeatedly heated to a cherry-brown heat in a heating furnace for direct firing, Figs. 29 and 30, or in a muffle furnace, Figs. 31 and 32, and allowed to cool completely, otherwise edge-cracks will be formed. After the destruction of the crystalline structure German silver can be worked like brass. Very thin sheet, $\frac{1}{40}$ to $\frac{1}{66}$ millimeter thick, is called *German silver foil* or *packfong foil.*

The sheets resting upon a carriage with perforated

bottom, running upon rails, are introduced into the heating furnace, Figs. 29 and 30, through an opening the entire

Fig. 29.

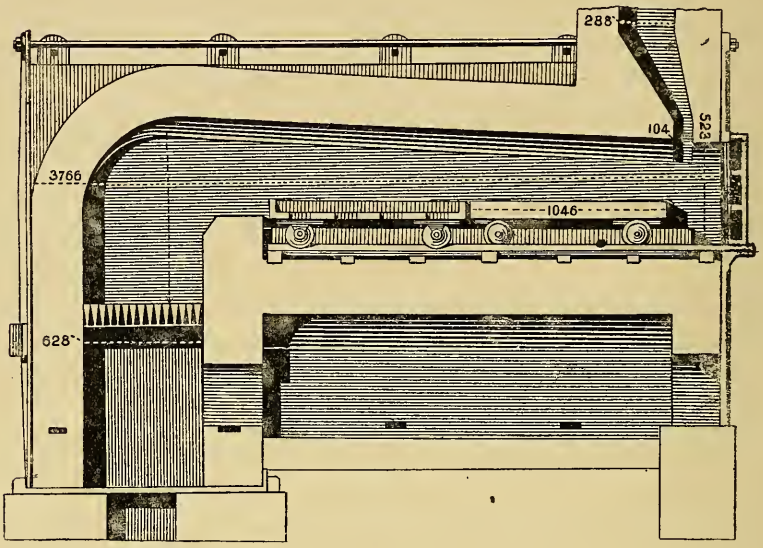
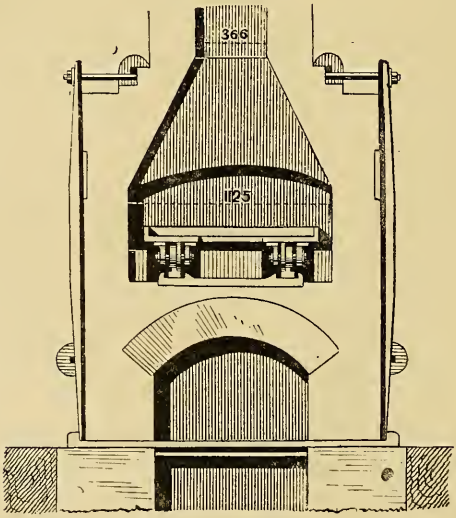


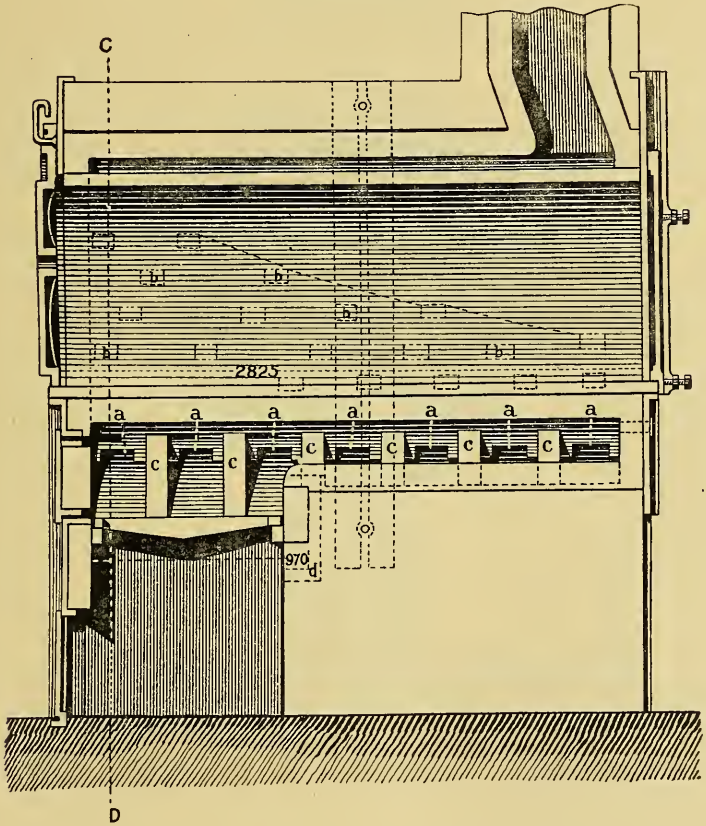
Fig. 30.



width of the furnace, which can be closed by a cast-iron door. When taken from the furnace the sheets are placed upon a carriage pushed close up to the furnace, the upper edge just level with the bottom of the hearth.

Muffle furnaces, Figs 31 and 32, are a protection against

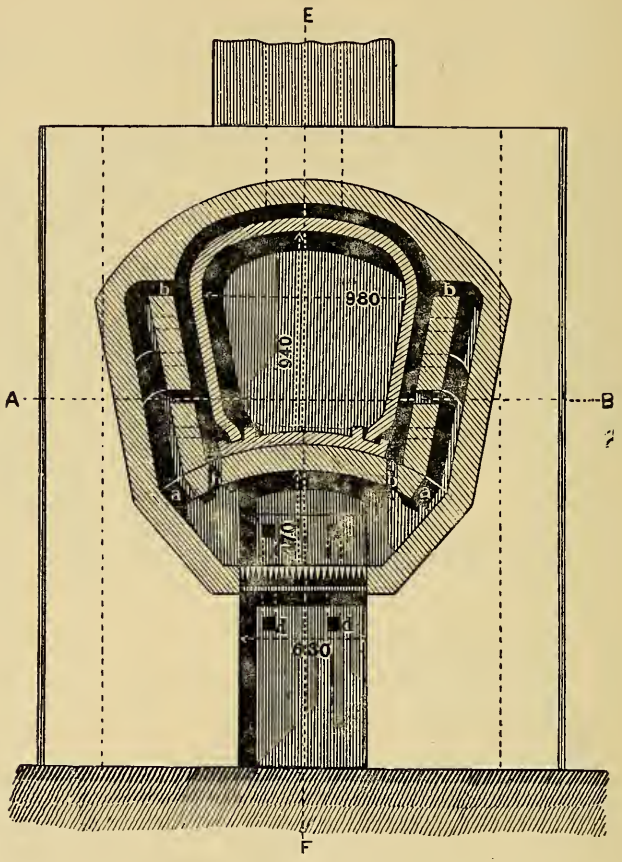
FIG. 31.



the deposit of dust, and allow of slower heating, but their effect is less favorable on account of their yielding the heat with greater difficulty. The cast iron muffle resting upon a fire-brick arch is washed by the gases of combustion ascending from the grate through the flues *a* and *b*. The

gases then pass into the chimney. The channels *d* serve for the introduction of air; *c* are the supports of the arch.

Fig. 32.



Nickel-zinc alloy.—Powdered nickel 1 part and powdered zinc 2 parts, when heated, yield an alloy of a blackish-violet powder and brittle metallic globules. A powder of zinc 90 parts and nickel 10 serves in painting, and for silver printing.

Nickel-tin alloy.—Such an alloy is obtained by heating 10 to 18 ozs. of nickel to a red heat, adding 2 lbs. of tin heated to 302° F., bringing the combined metals into 217

lbs. of tin heated to 302° F., and stirring. The alloy is hard and brittle.

Nickel-aluminium alloy.—An alloy of nickel 20 parts and aluminium 8 parts gives threads suitable for laces, etc.

Silver-bronze.—This term has been applied to an alloy for bars, sheet and wire. It is composed of manganese 18 parts, aluminium 1.20, silicon 5.00, zinc 13, and copper 67.50. It electrical resistance is claimed to be greater than that of German silver.

Nickel-aluminium alloys.—Solbisky prepares the following alloys which are distinguished by hardness, resistance to pressure and ductility. An addition of cadmium makes them elastic.

Parts.				Hardness Iron = 1000.
Aluminium.	Nickel.	Tin.	Copper.	
90	1	5	4	580
95	1	1	3	442
96.5	0.5	0.5	2.5	380

Rosëin. This alloy is used for jewelry. It is composed of nickel 40 parts, silver 10, aluminium 30, and tin 10.

Martino's hard alloys for drilling and cutting tools. Pig iron 17.25 parts, ferro-manganese 3, chromium 1.5, tungsten 5.25, aluminium 1.25, nickel 0.5, copper 0.75, wrought iron 70.5; or, pig iron 17.25 parts, ferro-manganese 4.5, chromium 2, tungsten 7.5, aluminium 2, nickel 0.75, copper 1, wrought iron 65.

Nickel-steel. In 1889, M. Henry Schneider, of Creuzot, France, took out two patents for the manufacture of alloys of cast iron and nickel, and steel and nickel respectively.*

In the specifications of the first patent it is stated that it

*U. S. Patents 415,657 and 415,655, Nov. 19, 1889.

is very difficult to incorporate nickel with iron and steel, particularly when it is attempted to produce these alloys on a commercial scale. To overcome this difficulty, a preliminary product is made of cast iron and nickel in a crucible, cupola, or open-hearth furnace. This product or alloy, while especially useful for the manufacture of iron and nickel and steel and nickel alloys, may be used as castings for a variety of purposes.

"In the manufacture of this alloy of cast-iron and nickel, a suitable furnace is charged with nickel scrap and ordinary cast or pig-iron, with carbonaceous matter; or the nickel may be in the form of nickelized compounds or coke. The operation is best carried on in a reverberatory furnace under a layer of anthracite, to avoid oxidation.

"The resulting alloy contains from five to thirty per cent. nickel, and is remarkable for its great elasticity and strength—properties which may be still further developed by chilling or tempering in the usual manner.

"This alloy of cast-iron and nickel, containing (say) thirty per cent. of nickel, sixty-three per cent. of iron, three per cent. of carbon, and two of manganese and silicon, is then charged on the bed of an open-hearth furnace, with the iron or scrap used in the ordinary methods of making open-hearth steel, care being taken to protect the bath from oxidation by means of a layer of slag or cinder. A steel, containing about five per cent. of nickel, is thereby obtained. Precautions, however, must always be taken to prevent red-shortness in the metal before the final introduction of the recarbonizing and maganiferous silico-spiegel iron or ferro-manganese.

"Nickel-steel of this kind, containing five per cent. of nickel is especially adapted or suitable for use in the construction of ordnance, armor plate, gun-barrels, projectiles and other articles employed for military or other like purposes, or the manufacture of commercial sheets, bars, etc.

"The percentages of carbon, silicon and manganese can

be regulated according to the degree of hardness required, but in all cases, in order to obtain the best results possible, the product must invariably be tempered in an oil or other bath." *

Marbeau's nickelo-spiegel is made by a patented process, which consists in the reduction of the ores of nickel, iron and manganese at the same time and in one operation. The following proportions are stated as affording good results. †

Nickel ore or matt, containing ten per cent. of nickel	2 tons
Manganese ore, containing ten per cent. manganese and forty per cent. iron	1 ton
Iron ore, containing fifty per cent. iron	12 cwt.

An alloy of nickel and iron having thus been obtained, there appears to be but little difficulty in working this nickel-iron into a nickel-steel by means of an open-hearth furnace.

Ferro-nickel and nickel-steel alloys for technical purposes are produced by adding metallic nickel to ingot-iron in a crucible, converter, or reverberatory furnace, or by melting in a blast-furnace oxide ores of iron, nickel and manganese. The *Société anonyme le Ferro-Nickel* of Paris, prepares in this manner an alloy of 20 per cent. nickel, 5 per cent. manganese, 72 per cent. iron, 2.5 to 3 per cent. carbon, and 0.5 per cent. phosphorus, sulphur and silicon. ‡

For the preparation on a large scale of 5 per cent. nickel-iron, ferro-nickel containing 25 per cent. of nickel is melted in a Martin furnace, ingot-iron is next added, then manganese and finally, previous to tapping, aluminium; for instance, 200 lbs. ferro-nickel, 800 lbs. ingot-iron, 6 lbs. ferro-manganese with 75 per cent. manganese and ½ lb. aluminium, total 1006.5 lbs. Leschesne proceeds in a similar manner.

* U. S. Patent, 415,655, Nov. 19, 1889.

† Engineering and Mining Journal, January 31, 1891.

‡ German patent No. 37376.

For the preparation of nickel-steel at Homestead, Pa., * nickelous oxide together with lime is brought upon the hearth of a Martin furnace, upon this ingot-iron and the rest of the charge. For alloys poorer in nickel, nickelous oxide and coal are made into bricks and brought into the furnace. In the Bethlehem works reducing coal is used or metallic nickel added for steel with 20 per cent. nickel.

Riley states the alloy (nickel-steel) can be made in any good open-hearth furnace, working at a fairly good heat. No special arrangements are required for casting, the ordinary ladles and moulds being sufficient. If the charge is properly worked, nearly all the nickel will be found in the steel—almost none is lost in the slag.

No extraordinary care is required when reheating the ingots for hammering or rolling. If the steel has been properly made, and is of correct composition, it will hammer and roll well, whether it contains little or much nickel. Riley appears to have obtained the best results with steel containing five per cent. nickel. With this grade rolled, but not annealed, he obtained elastic limit, 69,664 pounds per square inch, tensile strength 116,480 pounds per square inch, with fourteen per cent. elongation in eight inches. When rolled and annealed, elastic limit 72,800 pounds per square inch, tensile strength 104,832 pounds per square inch with thirteen and one-half per cent. elongation in eight inches.

Riley states that the whole series of nickel steels up to fifty per cent. nickel takes a good polish and finish. Steels rich in nickel are practically non-corrodible, and those poor in nickel are much better than other steels in this respect.

The alloys up to five per cent. of nickel can be machined with moderate ease; beyond that they are more difficult to machine.

The one per cent. nickel-steel welds fairly well, but this quality deteriorates with each addition of nickel.

* Stahl und Eisen, 1895. No. 15, p. 119.

The tests of some of the nickel steel made by Carnegie, Phipps & Co., Pittsburg, for the U. S. Navy Department, gave the following results: Elastic limit (two specimens) 59,000 and 60,000 lbs. per square inch, ultimate tensile strength, 100,000 and 102,000 lbs. per square inch; elongation, 15½ per cent., and reduction of area at fracture, 29½ and 26½ per cent. The test pieces were cut ¾ inch plate. The chemical analysis gave a content of $\frac{3}{16}$ per cent. nickel.*

The conductivity of nickel steel is extremely poor and low, but the resistance very high. According to Hopkinson, nickel steel containing less than 5 per cent. nickel is decidedly more magnetizable than wrought iron, particularly for high inductions. On the other hand, when containing 25 per cent. nickel, it is non-magnetic. But if cooled to —4° F. it becomes very decidedly magnetic and remains so when it again returns to its normal condition. If, finally, it is heated until it reaches its critical temperature, 1076° F., it becomes again non-magnetic and remains so until cooled to —4° F.†

*Engineering and Mining Journal, Dec. 13, 1890.

†F. Lynwood Garrison, Journal Franklin Inst., September, 1891.

CHAPTER XI.

ALUMINIUM ALLOYS.

As stated in the general review of the metals, aluminium is distinguished by a beautiful silvery color and great strength. It is, however, especially valuable on account of its low specific gravity, which is about that of glass.

Among the alloys of aluminium those with iron and copper are of special importance, but before entering on a description of them we will briefly mention the behavior of aluminium towards the other metals.

Aluminium unites easily with most of the metals, the combination being usually accompanied by a disengagement of heat, which is particularly active in the case of copper. Lead and antimony appear to be the only metals not alloying with it easily. The practical production of aluminium alloys is, generally speaking, not a difficult operation. The aluminium may be melted in a carbon or magnesia-lined crucible, without a flux, and the other metal simply thrown in; it falls to the bottom, melts, and is absorbed by the aluminium. In some few cases the alloying metal must be mixed in powder with finely-divided aluminium and heated together in a closed crucible, but this is only exceptionally the case. Again, a bar of aluminium may be taken in the tongs and held under the surface of another metal already melted. This is the best method of introducing small percentages of aluminium into other metals, unless we may except the adding of a small quantity of rich alloy to pure metal, thus diluting the percentage of aluminium to the desired quantity. Most of the alloys thus produced are improved by careful remelting, the aluminium seeming to become more intimately combined. The alloy made in the

first operation is often not entirely homogeneous, but becomes more uniform, and finally perfectly so, by repeated fusion. Very few of these alloys will liquate, the alloys in general acting as a single metal. However, in some cases where the alloy is not of a very definite or certain composition a liquation may take place, leaving as a residue an alloy with different proportions from the fluid metal running off. In the case of volatile metals they can usually be driven out of the aluminium by keeping the alloy melted and exposed to a heat sufficient to drive off the volatile metal.

The properties of the alloys of aluminium with the precious metals, gold and silver, approach nearest to those of the metal present in larger quantity. An alloy of aluminium 90 parts and gold 10 equals in hardness a corresponding alloy of gold and silver, and shows a beautiful yellow color. It can be readily worked under the hammer and rolled out to sheet. An alloy of aluminium with five parts of silver does not differ in its properties from pure aluminium, except that it is somewhat harder and takes a finer polish. It is used in making balances for chemists. With a content of iron of over five per cent., the aluminium becomes more refractory and, at the same time, brittle. The introduction of 0.1 per cent. of bismuth makes the metal so brittle that it can no longer be worked; it breaks even if worked directly after annealing. The presence of a small quantity of silicon gives to aluminium a strong crystalline structure, the crystallization being clearly perceptible on the surface by a peculiar net-like appearance of the metal.

Aluminium-iron alloys.—A small quantity of aluminium, by changing the structure of iron and steel, improves their strength, sensibly increases their resistance towards corroding substances and atmospheric influences, and lowers the fusing point, for instance of cast iron, making the castings more uniform and denser—for instance, Mitis castings.

Speaking generally of the application of aluminium to

the manufacture of iron and steel, the usual amount stated to be requisite for producing good results is about 0.10 per cent., but in many cases this would be too little.

Aluminium steel.—A considerable percentage of the total production of aluminium, both in this conntry and in Europe, is used in the manufacture of iron and steel castings. The process consists in adding from 0.10 to 0.15 per cent. of aluminium to iron and steel just before casting, by which blow-holes are prevented and sounder castings produced. The beneficial effect is due in part at least to the deoxidizing action of aluminium upon carbon monoxide at a high temperature, a reaction which has been demonstrated directly between the metal and the gas. A detail of manipulation in the method of applying aluminium, especially in castings for steam and pump cylinders, and other castings intended to resist high pressure, is reported in Dingler's Polytechnical Journal, Vol. 284, No. 11. The addition is made by first forming a mixture of aluminium and iron, which is effected by placing the proper quantity of heated aluminium in the bottom of a small ladle, running some iron into the ladle from the furnace, and waiting until the mixture begins to stiffen. Then the iron to be operated on is run into a large ladle and the iron-aluminium mixture is poured into it, whereby an intimate mixture of the whole is effected. For 220 lbs. of iron to be operated on, about 7 ozs. of aluminium are used. The iron is not poured at once from the large ladle, but is allowed to stand until it is orange-yellow and a thin film begins to form on the surface. As soon as this occurs the film is removed and the iron is poured. The mould should be kept full.

According to a paper read by Mr. J. W. Langley at the Glen Summit meeting of the American Institute of Mining Engineers, the practice in the United States in pouring ingots is as follows: The aluminium in small pieces of ¼ or ½ pound weight is thrown into the ladle during the

tapping, shortly after a small quantity of steel has already entered it. The aluminium melts almost instantaneously, and diffuses with great rapidity throughout the contents of the ladle. The diffusion seems to be complete. The quantity of aluminium to be employed will vary slightly, according to the kind of steel and the results to be attained. For open-hearth steel, containing less than 0.50 per cent. carbon, the amount will range from 5 to 10 ounces per ton of steel. For Bessemer steel the quantities should be slightly increased, viz., 7 to 16 ounces. For steel containing over 0.50 per cent. carbon, aluminium should be used cautiously; in general between 4 and 8 ounces to the ton.

Aluminium-copper alloys. — These two metals unite readily in any proportions, the union being attended with evolution of heat, which in some cases is very large in amount. The alloys of aluminium with copper show very different properties according to the quantities of aluminium they contain. Alloys containing but little copper cannot be used for industrial purposes. With 60 to 70 per cent. of aluminium they are very brittle, glass-hard, and beautifully crystalline. With 50 per cent. the alloy is quite soft, but under 30 per cent. of aluminium the hardness returns.

The usual alloys are those of 1, 2, 5 and 10 per cent. of aluminium, such alloys being known as *aluminium bronze.* The 5 per cent. bronze is golden in color, polishes well, casts beautifully, is very malleable cold or hot, and has great strength, especially after hammering. The 7.5 per cent. bronze is to be recommended as superior to the 5 per cent. bronze. It has a peculiar greenish-gold color, which makes it very suitable for decoration. All these good qualities are possessed by the 10 per cent. bronze. It is bright golden, keeps its polish in the air, may be easily engraved, shows an elasticity much greater than steel, and can be soldered with hard solder. When it is made by a simple mixing of ingredients, it is brittle and does not

acquire its best qualities until after having been cast several times. After three or four meltings it reaches a maximum, at which point it may be melted several times without sensible change. It gives good castings of all sizes and runs in sand-moulds very uniformly. Thin castings come out very sharp, but if a casting is thin and suddenly thickens, small off-shoots must be made at the thick place, into which the metal can run and then soak back into the casting as it cools and shrinks, thus avoiding cavities by shrinkage at the thick part. Its specific gravity is 7.68, about that of soft iron. Its strength when hammered is equal to the best steel. It may be forged at about the same heat as cast steel and then hammered until it is almost cold without breaking or ripping. Tempering makes it soft and malleable. It does not foul a file and may be drawn into wire. Any part of a machine which is usually made of steel can be replaced by this bronze.

The melting-point of aluminium-bronze varies slightly with the content of aluminium, the higher grades melting at a somewhat lower temperature than the lower. The 10 per cent. bronze melts at about 1700° F., a little higher than ordinary bronze or brass.

In making aluminium bronze great attention must be paid to the quality of the copper used. Ordinary commercial copper may contain small amounts of antimony, arsenic or iron, which the aluminium can in no way remove, and which affect very injuriously the quality of the bronze. The aluminium bronzes seem to be extremely sensible to the above metals, particularly to iron. This necessitates the employment of the very purest copper; electrolytic copper is sometimes used when not too high priced, but Lake Superior is generally found satisfactory enough. Even the purest copper may contain dissolved cuprous oxide or occluded gases, and it is one of the functions of the aluminium to reduce these oxides and gases, forming slag which rises to the surface and leaving the

bronze free from their influences. If tin occurs in the copper, it lowers very greatly the ductility and strength of the bronzes, but zinc is not so harmful.

Care should also be taken as to the purity of the aluminium used, though its impurities are not so harmful as they would be if occurring in similar percentage in the copper, since so much more copper than aluminium is used in these alloys. Yet the bronzes are so sensitive to the presence of iron that an aluminium with as small a percentage of this metal as possible should be used. The silicon in commercial aluminium is not so harmful as the iron, but it does harden the bronze considerably and increases its tensile strength. The "Magnesium and Aluminium Fabrik" of Hemelingen gives the following directions for preparing the bronzes: Melt the copper in a plumbago crucible and heat it somewhat hotter than its melting point. When quite fluid and the surface clean, sticks of aluminium of a suitable size are taken in tongs and pushed down under the surface, thus protecting the aluminium from oxidizing. The first effect is necessarily to chill the copper more or less in contact with the aluminium; but if the copper was at a good heat to start with, the chilled part is speedily dissolved and the aluminium attacked. The chemical action of the aluminium is then shown by a rise in temperature which may even reach a white heat; considerable commotion may take place at first, but this gradually subsides. When the required amount of aluminium has been introduced, the bronze is let alone for a few moments, and then well stirred, taking care not to rub or scrape the sides of the crucible. By the stirring, the slag, which commenced to rise even during the alloying, is brought almost entirely to the surface. The crucible is then taken out of the furnace, the slag removed from the surface with a skimmer, the melt again stirred to bring up what slag may still remain in it, and is then ready for casting. It is very injurious to leave it longer in the fire than is absolutely neces-

sary; also any flux is unnecessary, the bronze needing only to be covered with charcoal powder. The particular point to be attended to in melting these bronzes is to handle as quickly as possible when once melted.

As with ordinary brass or bronze, two or three remeltings are needed before the combination of the metals appears to be perfect, and the bronze takes on its best qualities. When the alloy is thus made perfect, the bronze is not altered by remelting, and the aluminium which in the first instance removed the dissolved oxides and occluded gases from the copper, now prevents the copper from taking them up again, and so keeps the bronze up to quality. If, however, the bronze is kept melted a long time, and subject to oxidizing influences, the tendency of the copper to absorb oxygen will cause some loss of aluminium by the action of the latter in removing the oxygen taken up, and a slag consisting principally of alumina will result; but if the remelting of the bronze is done quickly and the surface covered with charcoal or coke, the loss from this cause will be very trifling, and the percentage of aluminium will remain practically constant.

Dilution of a high per cent. bronze to a lower one is practiced on a large scale by the companies which produce aluminium bronze directly in their reduction furnaces. The operation is said to consist simply in melting the high per cent. bronze in a crucible, and stirring into it pure copper in the required proportion, or else melting the two down together on the hearth of a reverberatory furnace. The combined aluminium thus cleanses the added copper and produces a lower per cent. bronze of right quality if the high per cent. bronze is pure and the copper added of the proper quality. It is, of course, quite certain that no difficulty can occur in adding aluminium to a low per cent. bronze to increase its percentage other than that of imperfect combination which may be overcome by one or two remeltings.

Aluminium bronze is not an easy metal to cast perfectly until the molder is familiar with its peculiarities. Aluminium bronze shrinks about twice as much as brass, and this shrinkage in setting and this contraction in cooling are the obstacles which cause the most trouble. A plumbago crucible, or one lined with magnesite,* is the best to use for melting the bronze, the melt being kept covered with powdered charcoal. Dr. Joseph W. Richards suggests that the stirrers and skimmers used be coated with a wash made of plumbago and a little fire-clay, as the contact of bronze with bare iron tools cannot but injure its quality. The crucible should not be kept in the fire any longer than is absolutely required to bring the bronze to proper heat for casting. In casting it is of considerable advantage to use a casting ladle, into which the bronze is poured, which is arranged so as to tap from the bottom. This effectually keeps any slag or scum from being entangled in the casting. The same result is also obtained by arranging a large basin on top of the pouring gate, which is temporarily closed by an iron or clay stopper. Enough bronze is then poured into this basin to fill the mould, and after the dirt is all well up to the surface, the plug is withdrawn and the mould fills with clean metal. For very small work the ordinary skim-gate will answer the above purpose; for larger castings the tapping ladle is preferred. Plain castings, such as pump-rods, shafting, etc., and especially billets for rolling and drawing, are cast advantageously in iron moulds, which should be provided with a large sinking head on top to feed the casting as it cools. Rubbing with a mixture of plumbago, kaolin and oil is said to protect the

* It is best to use the white Grecian mineral, fully shrunk by calcining at the highest heat of a fire-brick or porcelain kiln, and then ground fine and made into a stiff paste with sugar syrup or molasses. The crucible is carefully lined, and then heated slowly to redness. On cooling any cracks are carefully filled with more paste, and the crucible is baked again; when properly prepared, however, one baking is sufficient, and the linings do not shrink from the walls of the crucible.

iron moulds from sticking. The chilling makes the bronze soft, and the slabs and cylinders thus cast for rolling and drawing are in good condition to be worked at once. For ordinary foundry castings, sand moulds are used. The slower cooling makes the castings more or less hard; if soft castings are wanted they can be subsequently annealed.*

Thomas D. West, the author of "American Foundry Practice," in a paper on "Casting Aluminium Bronze and other Strong Metals," read before the American Society of Mechanical Engineers, says:

"The difficulties which beset the casting of aluminium bronze are in some respects similar to those which were encountered in perfecting methods for casting steel. There is much small work which can be successfully cast by methods used in the ordinary moulding of cast iron, but in peculiarly proportioned and in large bronze castings other means and extra display of skill and judgment will generally be required. In strong metals there appears to be a 'red shortness' or degree of temperature after it becomes solidified, at which it may be torn apart if it meets a very little resistance to its contraction, and the separation may be such as cannot be detected by the eye, but will be made known only when pressure is put upon the casting. To overcome this evil and to make allowance for sufficient freedom in contraction, much judgment will often be required and different modes must be adopted to suit varying conditions. One factor often met with is that of the incompressibility of cores or parts forming the interior portion of castings, while another is the resistance which flanges, etc., upon an exterior surface oppose to freedom of contraction of the mass. The core must generally be 'rotten' and of a yielding character. This is obtained by using

*ALUMINIUM: Its History, Occurrence, Properties, Metallurgy, and Applications, Including Its Alloys. By Joseph W. Richards. Third edition, Revised and Enlarged. 1896. Philadelphia, Henry Carey Baird & Co.

rosin in coarse sand, and filling the core as full of cinders and large vent-holes as possible, and by not using any core-rods of iron. The rosin would cause the core when heated to become soft, and would make it very nearly as compressible as a 'green-sand' core when the pressure of the contraction of the metal would come upon it.

"By means of dried rosin or green sand cores we were able to meet almost any difficulties which might arise in ordinary work from the evils of contraction, so far as cores were concerned. For large cylinders or castings, which might require large round cores which could be 'swept,' a hay-rope wound around a core barrel would often prove an excellent yielding backing, and allow freedom for contraction sufficient to insure no rents or invisible strain in the body of the casting. To provide means of freedom in the contraction of exterior portions of castings, which may be supposed to offer resistance sufficient to cause an injury, different methods will have to be employed in almost every new form of such patterns. It may be that conditions will permit the mould to be of a sufficiently yielding character, and again it may be necessary to dig away portions of the mould or loosen bolts, etc., as soon as the liquid metal is thought to have solidified. In any metal there may be invisible rents or strains left in a casting through tension when cooling, sufficient to make it fragile or crack of its own accord, and this is an element which, from its very deceptive nature, should command the closest attention of all interested in the manufacture of castings.

"Like contraction, the element of shrinkage is often found seriously to impede the attaining of perfect castings from strong metals. In steel castings much labor has to be expended in providing risers sufficient to 'feed solid' or prevent 'draw-holes' from being formed, and in casting aluminium-bronze a similar necessity is found. The only way to insure against the evils of shrinkage in this metal was to have the 'risers' larger than the body or part of the

castings which they were intended to 'feed.' The feeder or riser being the largest body, it will, of course, remain fluid longer than the casting, and, as in cast-iron, that part which solidifies first will draw from the nearest uppermost fluid body, and thus leave holes in the part which remains longest fluid. The above principle will be seen to be effective in obtaining the end sought. It is to be remembered that it is not practicable to 'churn' this bronze, as is done with cast iron. A long cast-iron roll, 1 foot in diameter, can by means of a feeder 5 inches in diameter and a ½ inch wrought-iron rod be made perfectly sound for its full length. To cast such a solid in bronze, the feeding head should be at least as large as the diameter of the roll, and the casting moulded about one-quarter longer than the length of roll desired. The extra length would contain the shrinkage hole, and when cut off a solid casting would be left. This is a plan often practised in the making of guns, etc., in cast iron, and is done partly to insure against the inability of many moulders to feed solid and to save that labor. A method which the writer found to work well in assisting to avoid shrinkage in ordinary castings in aluminium bronze was to 'gate' a mould so that it could be filled or poured as quickly as possible, and to have the metal as dull as it would flow to warrant a full run of casting. By this plan very disproportionate castings were made without feeders on the heavier parts, and upon which draw or shrinkage holes would surely have appeared had the metal been poured hot.

"The metal works well in our ordinary moulding sands and 'peels' extra well. As a general thing, disproportionate castings weighing over 100 pounds are best made in 'dry' instead of 'green' sand moulds, as such will permit of cleaner work and a duller pouring of the metal, for in this method there is not that dampness which is given off from a green-sand mould and which is so liable to cause 'cold shots.' When the position of the casting work will

permit, many forms which are proportionate in thickness can be well made in green-sand by coating the surface of the moulds and gates with 'silver-lead' or plumbago.

"From 'blow-holes,' which are another characteristic element likely to exist in strong metals, it can be said that aluminium-bronze is free. Should any exist, it is the fault of the moulder or his mould, as the metal itself runs in iron moulds as sound and close as gold. Sand moulds to procure good work must be well vented, and, if of 'dry-sand,' thoroughly open sand mixture should be used and well dried. The sand for 'green-sand' work is best fine, similar to that which will work well for brass castings. For 'dry-sand' work the mixture should be as open in nature as possible, and, for blacking the mould, use the same mixtures as are found to work well with cast iron."

Aluminium bronze forges similarly to the best Swedish iron but at a much lower temperature. It works best at a cherry red; if this is much exceeded, the metal becomes hot-short, and is easily crushed. The temperature for rolling is a bright red heat, and it is a curious fact that if the metal were forged at the temperature at which it is rolled, it would be crushed to pieces. If the temperature in the ordinary muffle in which it is heated be allowed to rise too high, the bronze will frequently fall apart by its own weight. When in the rolls it acts very much like yellow Muntz metal. As it loses its heat much more rapidly than copper or iron, it has to be annealed frequently between rollings.

The following examples of rolling are given by the "Cowles Electric Smelting and Aluminum Company": A billet of 10 per cent. bronze about 18″ x 1¼″ x 1¼″ was rolled in a Belgian train to quarter-inch rod, at one annealing. The 5 per cent. bronze is harder to roll hot than the 10 per cent., but in cold rolling just the reverse is true; a piece of 5 per cent. sheeting, 8 inches wide, has been reduced 8 gauge numbers when rolled cold at one annealing;

while a 10 per cent. sheet could not be reduced more than half that number. The billets for rolling can be best prepared by casting in iron moulds previously rubbed with a mixture of plumbago, pipe-clay, and lard oil. The metal chills very quickly, and very smooth castings can be produced, the smoothness depending considerably on the speed of pouring. With care the 5 and 10 per cent. bronzes can be easily drawn into wire. It is preferable, however, to roll the 5 per cent. to quarter inch rods, and the 10 per cent. to a less diameter, and anneal them. The metal thus prepared is much tougher and less liable to break in drawing. The dies must be very hard, or the ordinary wire, and especially the higher grades, are apt to cut them. The speed of the draw blocks must be less than for iron, brass, copper, German silver, or soft steel, and the reduction must be more gradually effected.

Aluminium bronze is, in every respect, considered the best bronze yet known. Its rather high cost formerly prevented its extensive use in the arts, but since the perfection of processes for the production of aluminium, the cost of manufacture has been greatly reduced.

The following results were obtained at the South Boston Iron Works, with pieces of the Cowles Company alloys:

Aluminium bronze.	Tensile strength, pounds per square inch.	Elastic limit.	Elongation, per cent.
10 per cent. bronze	91,463	—	1½
10 " "	92,441	59,815	2½
10 " "	96,434	85,034	1
9 " "	77,062	51,774	9
9 " "	71,698	44,025	9
8½ " "	72,019	—	28½
7½ " "	60,716	45,537	6

The following tests were made at the Washington Navy Yard of pieces very nearly half an inch in diameter and two inches between shoulders:

Aluminium bronze.	Tensile strength, pounds per square inch.	Elastic limit.	Elongation, per cent.
10 per cent. bronze	114,514	—	0.45
10 " "	95,366	69,749	0.05
10 " "	109,823	79,894	0.05

According to Thurston, the alloys of aluminium and copper may be made by fusing together the oxides with metallic copper and enough carbon and flux to reduce them. The oxides as well as the other materials should be as finely divided as possible, and the carbon introduced in excess.

Aluminium brass. An addition of aluminium (1.5 to 5.8 per cent.) to brass increases its strength, toughness and elasticity. An alloy of copper 60 parts, zinc 30, and aluminium 2, made by the aluminium factory at Hemlingen near Bremen, can be rolled, forged, stamped, drawn into tubes and wire, is suitable for bells, strings, etc., and especially for cartridge shells, they being not attacked by the gases of the powder. With an addition of 8 per cent. aluminium the brass becomes more ductile, acquires a more beautiful color, and becomes stronger and more resistant towards caustic fluids. With over 13 per cent. aluminium it becomes hard and red-short, and acquires a reddish color. With a still greater content of aluminium it becomes very brittle and gray-black, but at 25 per cent. the strength, according to Langhove, increases again.

According to Kiliani the action of aluminium upon brass is much more powerful than upon bronze; 1 to 3 per cent. of it producing nearly the same effect in the former as 5 to 10 per cent. in the latter, so that aluminium-brass is the cheaper metal. Compared with aluminium-bronze, aluminium-brass has the disadvantage of greater weight and of being more readily oxidized, it being, however, less oxidizable than many other metals used at the present time. For

soft brass alloys ¼ to 2 per cent. aluminium is usually taken; for hard alloys 2 to 3.5 per cent. While in casting ordinary brass a dirty-green coat of oxide is obtained, with an addition of only ¼ per cent. aluminium the surface remains bright and lustrous, and the metal itself becomes more liquid. By the addition of 1 per cent. aluminium the tensile strength of brass with 33 per cent. zinc is greater than that of cast delta metal. The content of zinc exerts an essential influence upon the alloy; the greater it is the smaller the addition of aluminium must be, otherwise the alloy will be too hard and brittle. To brass with 33 per cent. zinc, up to 3.5 per cent. aluminium is generally added, and to brass with 40 per cent. zinc, not over 2 per cent. While alloys with 40 per cent. zinc can, without regard to their content of aluminium, be forged at a dark red heat, those with 33 per cent. zinc must contain at least 2 to 3½ per cent. aluminium to be malleable at a dark red to brown heat. With the decrease in the content of aluminium the forging temperature also decreases, so that brass containing 1 per cent. should be forged only hand-warm, and brass with ½ per cent. cold. Brass with 33 per cent. zinc and 3 to 4 per cent. aluminium can be forged at a dark cherry-red heat, while at this temperature ordinary brass breaks up under the hammer.

The aluminium may be added to the fusing brass either as such, or in the form of a 20 or 25 per cent. aluminium bronze. In remelting aluminium-brass an enrichment of aluminium takes place in consequence of the volatilization of zinc. Casting requires experience, on account of the great shrinkage and the formation of froth, the latter readily passing into the alloy. A warm alloy when suddenly cooled becomes brittle and the fracture exhibits a deep golden lustrous color.

Messrs. Cowles recommended aluminium brass for the following purposes:

"Valve and valve-seats for mining pumps, or pumps

working under great pressure, worms and worm-wheels, slide-faces, mining machinery, pinions, screws, hydraulic machinery, dredging machinery, gates for turbine wheels working under a high head, propeller wheels, and as a metal to resist the action of salt water in marine architecture. While aluminium brass is not quite as strong or as tough as the A grade bronze, yet it will answer nearly as well for many purposes that the bronze is used for."

The ordinary grades of aluminium brass have about 85,000 pounds per square inch in tensile strength, with nine per cent. elongation.

Cowles Bros. report the following series of tests made, at their works in Lockport, their alloys all being made by adding zinc to aluminium-bronze:

Composition.			Tensile strength per square inch (castings).	Elongation, per cent.
Aluminium.	Copper.	Zinc.		
5.8	67.4	26.8	95,712	1.0
3.3	63.3	33.3	85,867	7.6
3.0	67.0	30.0	67,341	12.5
1.5	77.5	21.0	32,356	41.7
1.5	71.0	27.5	41,952	27.0
1.25	70.0	28.0	35,059	25.0
2.5	70.0	27.5	40,982	28.0
1.0	57.0	42.0	68,218	2.0
1.15	55.8	43.0	69,520	4.0

Richards bronze.—The alloy known under this name is the invention of Mr. Joseph Richards, of Philadelphia. It is a very strong and at the same time cheap alloy. It contains copper 55 parts, zinc 42 or 43, iron 1, aluminium 1 to 2. This alloy is of a golden-yellow color, is exceedingly fine-grained, and has a tensile strength in castings of 50,000 lbs. per square inch with 15 per cent. elongation. Like all the strong brasses, however, it requires some experience in handling before the ordinary metal-worker can turn out uniform castings with these maximum properties. The worked metal averages 50 per cent. stronger.

Aluminium-nickel-copper alloys.—A number of remarkable and useful alloys are made by mixing aluminium bronzes with nickel in various proportions. These compositions are said to be very ductile and to have a tenacity of from 75,000 to over 100,000 lbs. per square inch, with about 30 per cent. elongation. Tests made by Kirkaldy on alloys of a similar nature made by the "Webster Crown Metal Company," England, gave results ranging from 82,000 to over 100,000 lbs. per square inch with 20 to 30 per cent. elongation.

The alloys are prepared as follows:

a. Copper is melted and aluminium added to it until a 10 per cent. bronze is made. There is then added to it 1 to 6 per cent. of an alloy, ready prepared, containing:

Copper	20 parts.
Nickel	20 "
Tin	30 "
Aluminium	7 "

The alloy thus prepared would contain, as represented by the two extremes:

	I.	II.
Copper	89.3	86.4
Nickel	0.3	1.4
Tin	0.4	2.0
Aluminium	10.0	10.2

b. The two following alloys are prepared in the usual way, under a flux consisting of equal parts of potassium and sodium chlorides, and are cast into bars:

I.		II.	
Aluminium	15 parts	Nickel	17 parts
Tin	85 "	Copper	17 "
		Tin	66 "
	100 parts		100 parts

To make the bronzes, equal parts of these two alloys are

melted with copper; the more of the alloys used the harder and better the bronze. The best mixture is of

Copper	84 parts
Alloy I	8 "
Alloy II	8 "
	100 parts

The copper is first melted, then the alloys put in together and stirred well. As iron is harmful to this bronze, the stirrer should be of wood or clay. This alloy is suitable for art castings, kitchen utensils, etc., or anywhere where durability, hardness, malleability, polish and very slight oxidability are required. A cheaper and more common alloy may be made of

Copper	91 parts
Alloy I	4 "
Alloy II	5 "

The two bronzes would contain centesimally:

	Rich alloy.	Poorer alloy.
Copper	85.36	94.58
Tin	12.08	6.70
Nickel	1.36	3.85
Aluminium	1.20	0.60

c. The following alloy is said to withstand oxidation well, to possess great tenacity, durability, capability to bear vibration, and to take a high polish. A preliminary alloy is made of:

Copper	200 parts
Tin	80 "
Bismuth	10 "
Aluminium	10 "

The alloy proper is made by melting together:

Preliminary alloy	4½ parts
Copper	164 "
Nickel	70 "
Zinc	61½ "

The final composition would be by calculation:

Copper	55.67
Nickel	23.33
Zinc	20 50
Tin	0.40
Bismuth	0.05
Aluminium	0.05
	100.00

d. Another alloy patented by Mr. Webster contains:

Copper	53	parts	= 51.0	per cent.
Nickel	22½	"	= 21.6	"
Zinc	2	"	= 21.2	"
Tin	5	"	= 4.8	"
Bismuth			= 0.7	"
Aluminium			= 0.7	"
			100.00	"

Lechesne.—The alloy known under this name has been patented in England by the Société anonyme la Ferro-Nickel, of Paris. The patent specified two alloys containing:

	I.	II.
Copper	900 parts	600 parts
Nickel	100 "	400 "
Aluminium	1¾ "	½ "

Which would give in per cent.:

	I.	II.
Copper	89.84	59.97
Nickel	9.98	39.98
Aluminium	0.18	.05
	100.00	100.00

The first of these alloys is the one to which the name "Lechesne" appears to be given. In a description of the manufacture of this alloy, a French magazine states that the nickel is first put into a crucible and melted, the copper stirred in gradually, then the heat raised and the aluminium

added. The alloy is heated almost to boiling and cast very hot. This alloy is claimed to be equal to the best quality of German silver, being very malleable, homogeneous, strong and ductile, and stands hammering, chasing, punching, etc.

The following alloys have been recommended by G. F. Andrews as being all very hard, fine-grained and possessing great strength.

	Aluminium.	Nickel.	Copper.
No. I	6¼	21¼	72½
No. II	10	24	66
No. III	12	33	55

No II. has the color of 10-carat gold and takes a fine polish. No III. has a beautiful golden-brown color. No. I. is similar in color but of a richer and deeper tone. These alloys may be very useful for decorative purposes.

Sun-bronze.—An alloy known under this name is composed of cobalt 60 or 40 parts, aluminium 10, copper 30 or 50.

Metalline.—This alloy contains cobalt 35 parts, aluminium 25, iron 10, copper 30.

*Aluminium alloy for dentists' fillings.**—Silver 12.3, per cent., tin 52, copper 4.7, aluminium 1. It is reduced to a powder and then forms an amalgam with mercury.

Alloy for type metal.†—Lead 65 parts, antimony 20, and 10 parts of an alloy consisting of equal parts of tin, copper, and aluminium. The tin-copper-aluminium alloy is first melted, the antimony added to it, and the mixture is then added to the melted lead.

Aluminium alloy for type metal.‡—Aluminium 72 to 90 per cent., copper 2 to 10 per cent., and tin 2 to 23 per cent.

Aluminium-nickel bronze.§—A small quantity of magnesium is added to aluminium-nickel bronze, the following

* U. S. patent, 475,382, May 24, 1892.

† U. S. patent, 463,427, Nov. 11, 1891.

‡ German patent, 101,020.

§ English patent, 5,568, 1898.

proportions being the best: Copper 89 to 98 per cent., aluminium and nickel 2 to 11 per cent. To this is added, phosphorus up to 0.5 per cent. and magnesium up to 1.5 per cent. This alloy is claimed to be especially suitable for locomotive furnaces, fire-tubes, etc., as well as for castings, such as cocks, valves, bearings, etc.

Partinium.—The alloy known under this name is an aluminium-tungsten alloy and is extensively used in France in the construction of motors, etc. It is cheaper than aluminium, nearly as light, and possesses greater power of resistance. Cast partinium has a specific gravity = 2.89, and rolled partinium one = 2.89. It is claimed to have a tensile strength of 32 to 37 kilogrammes per square millimeter.

*Aluminium-bronze alloy.** —Aluminium 12 to 25 parts, manganese 2 to 5, copper 75 to 85.

Hercules' metal.—An alloy known under this name consists of bronze 88 per cent., aluminium 2½, tin 7½, and zinc 2.

Aluminium-chromium alloy.—With chromium aluminium forms a beautiful alloy which can be prepared by a rather tedious operation in the form of crystalline needles. It has thus far found no technical application.

Aluminium-magnesium alloy called magnalium.†—This alloy which is used for various purposes is made by adding 2 to 10 parts of magnesium to 100 parts aluminium. It forms an exception to the general rule that aluminium alloys are specifically heavier than pure aluminium. Alloys with 6 per cent. magnesium are specifically not heavier than aluminium, and with a higher percentage lighter. Alloys with 3 to 10 per cent. magnesium have two to two and half times the strength of pure aluminium, but a higher percentage of magnesium decreases the strength. Brittle-

* U. S. patent, 446,351, Feb. 10, 1891.

† German patent 113,935. U. S. patent 62,3084.

ness increases quite rapidly with the content of magnesium, and alloys with more than 20 per cent of it are useless by reason of their great brittleness, while those with 3 to 4 per cent. of magnesium are malleable and can be worked. However, like pure aluminium, they possess the drawback of not being readily worked with cutting tools and clogging the file. By subjecting, however, the alloys to a process of compression by rolling, drawing, pressing, etc., the remarkable fact becomes evident that they acquire entirely different properties. They possess the same properties as pure aluminium treated in the same manner, which otherwise can be attained only with larger additions of magnesium to aluminium, *i. e.*, an alloy with a small content of magnesium can readily be worked with cutting tools. The process of rolling is executed as follows: The alloys are first passed once or several times cold through the rolls, then heated to about 752° to 932 F., again passed once or several times, cold, through the rolls and this alternate heating and rolling is repeated till the desired strength has been attained.

Aluminium-magnesium alloy for reflectors,* which, when polished, possesses also a strong reflecting power for the ultra-violet rays, consists of aluminium 100 parts, magnesium 60 to 200.

Alloy of aluminium and tin.—An alloy, the use of which it is claimed overcomes the difficulties of working and welding aluminium, is formed by melting together 100 parts of aluminium with 10 of tin. The alloy is whiter than aluminium and but little heavier, its specific gravity being 2.85. By most substances it is less attacked than pure aluminium, and it can be welded and soldered like brass without any special preparation.

Brazing aluminium bronze.—Aluminium-bronze will braze as well as any other metal, using one-quarter brass

* German patent 110,178.

solder (zinc 50 per cent., copper 50 per cent.) and three-quarters borax.

Soldering aluminium-bronze.—To solder aluminium-bronze with ordinary soft (pewter) solder: Cleanse well the parts to be joined free from dirt and grease. Then place the parts to be soldered in a strong solution of sulphate of copper, and place in the bath a rod of soft iron touching the parts to be joined. After a while a copper-like surface will be seen on the metal. Remove from bath, rinse quite clean, and brighten the surfaces. These surfaces can then be joined by using a fluid consisting of zinc dissolved in hydrochloric acid, in the ordinary way with common soft solder.

Mierzinski recommends ordinary hard solder, and says that Hulot uses an alloy of the usual half-and-half lead-tin solder with 12.5, 25, or 50 per cent. of zinc amalgam.

Aluminium-bronze for jewelry may be soldered by using the following composition:

Hard solder for 10 *per cent. aluminium-bronze.*—Gold 88.88 per cent., silver 4.68, copper 6.44.

Middling hard solder for 10 *per cent. aluminium-bronze.*—Gold 54.40 per cent., silver 27.60, copper 18.

Soft solder for aluminium-bronze.—Brass (copper 70 per cent., tin 30 per cent.) 14.30, gold 14.30, silver 57.10, copper 14.30.

Schlosser gives the following directions for preparing solder for aluminium-bronze: White solder is alloyed with zinc amalgam in the proportions of

White solder	2	4	8
Zinc amalgam	1	1	1

The white solder may be composed as follows:

Brass	40	22	18
Zinc	2	2	12
Tin	8	4	30

The zinc amalgam is made by melting 2 parts of zinc, adding 1 part of mercury, stirring briskly and cooling the amalgam quickly. It forms a silver white, very brittle alloy. The white solder is first melted, the finely powdered zinc amalgam added, and the alloy stirred until uniform, and poured into bars.

Soldering aluminium.—Although strictly speaking the subject of soldering aluminium-bronze and aluminium does not belong here, a special chapter being devoted to "Soldering," it is preferred to refer to it in this place.

From the articles which occasionally appear in the trade journals, both in Europe and in this country, and the patent list, it appears that the difficulties of soldering aluminium have not been entirely overcome. Some of the solders are here introduced without comment.

Mourey's aluminium solders are composed of :—

	I.	II.	III.	IV.	V.
Zinc	80	85	88	90	94
Copper	8	6	5	4	2
Aluminium	12	9	7	6	4

In making these solders the copper should be melted first, the aluminium then added, and the zinc last. Stearin is used as a flux to prevent the rapid oxidation of the zinc. When the last metal is fused, which takes place very quickly, the operation should be finished as rapidly as possible by stirring the mass, and the alloy should then be poured into an ingot-mould of iron, previously rubbed with fat. The pieces to be soldered should first be cleaned thoroughly and roughened with a file and the solder placed on the parts in small fragments, the pieces being supported on a piece of charcoal. The place of juncture should then be heated with the blast lamp. The union is facilitated by the use of a soldering tool of aluminium. This last is said to be essential to the success of the operation.

Alloy I is recommended for small objects of jewelry;

alloy IV is said to be best adapted for larger objects and for general work, and is that most generally used. The successful performance of the act of soldering appears to require skill and experience, but the results obtained are said to leave nothing to be desired. Soldering tools of copper or brass should be avoided, as they would form colored alloys with the aluminium and solder. The skillful use of the aluminium tool, however, requires some practice. At the instant of fusion the operator must apply some friction, and, as the solder melts very suddenly, the right moment for this manipulation may be lost unless the workman is experienced.

Bourbouze's aluminium solder. Tin 45, aluminium 10. If the soldered articles are not to be subjected to further working, a solder containing somewhat less aluminium may be used.

Frishmuth's aluminium solders.

	I.	II.
Silver	10	—
Copper	10	—
Aluminium	20	—
Tin	60	95 to 99
Zinc	90	—
Bismuth	—	5 to 8

Solder No. II. is to be applied with the soldering iron, but on account of its great fusibility it appears to be only suitable for small articles, which after soldering are not to be subjected to further heating.

M. H. Lancon has patented* the following method of preparing aluminium solder: Pure aluminium is melted, the surface of the melted metal completely covered with a layer of phosphoric acid, acid sodium sulphate, fluorine combinations or other salts of an acid reaction, and finally a small quantity of copper and tin is added to the melted metal, or copper, bismuth, zinc and tin, or copper, antimony, bismuth

* German patent, 66,398.

and zinc, or copper, antimony, bismuth and tin. The composition of the solder varies according to the articles to be soldered.

For wire and thin articles the solder is composed of pure aluminium 95 parts, copper 1, tin 4. The 4 parts tin may be replaced by bismuth 2 parts, zinc 1, tin 1.

For large pieces of aluminium and aluminium sheets, the solder is composed of: Pure aluminium 95 parts, copper 2, antimony 1, bismuth 1, zinc 1; *or:* Pure aluminium 60, copper 13, bismuth 10, antimony 15, tin 2.

Schlosser recommends two solders containing aluminium as especially suitable for soldering dental work on account of their resistance to chemical action. Copper cannot be allowed in alloys intended for this use, or only in very insignificant quantity, since it is so easily attacked by acid food, etc. Since these two alloys can probably be used also for aluminium dental work, their composition is here given:

Platinum aluminium solder.—Gold 30, platinum 1, silver 20, aluminium 100.

Gold aluminium solder.—Gold 50, silver 10, copper 10, aluminium 20.

O. M. Thowless has patented the following solder for aluminium and the method of applying it.* The alloy is composed of: Tin 55 parts, zinc 23, silver 5, aluminium 2.

The aluminium and silver are first melted together, the tin added, and lastly the zinc. The metallic surfaces to be united are immersed in dilute caustic alkali, or a cyanide solution, washed and dried. They are then heated over a spirit lamp, coated with the solder, and clamped together, small pieces of the alloy being placed around the joints. The whole is then heated to the melting point of the solder, and any excess of it removed. No flux is used.

C. Sauer of Berlin has patented the following: An alloy is made of: Aluminium 9 parts, silver 1, 2, 3, or 4, copper 2, 3, 4, or 5.

*English patent, 10,237, Aug. 29, 1885.

He also claims the above alloy, to which is added 1 to 2 parts of zinc, cadmium, or bismuth, or even a fusible metal such as Wood's alloy. A small proportion of gold may be added. In making, the copper and silver are first melted, melted aluminium added, and the solid zinc last dropped in. In using, the alloy is broken small, spread between the surfaces to be soldered, previously heated, and the joint then made with a soldering iron. No flux is required.

Chloride of silver has been recommended as a solder. It is to be finely powdered and spread along the junction to be soldered, and melted with the blow-pipe.

Richards's solder.—Mr. Joseph Richards has patented * in the United States and England a composition containing a small amount of phosphorus, and describes as preferable a solder composed of:

Tin	32 parts	= 78.34	per cent.	tin.
Zinc	8 "	= 19.04	"	zinc.
Aluminium	1 "	= 2.38	"	aluminium.
Phosphor tin	1 "	= 0.24	"	phosphorus.

On remelting some of this solder, a liquation was noticed, and it was inferred that the more fusible part was probably a better alloy for soldering, being less likely itself to liquate. It was therefore analyzed, and found to contain 71.65 per cent. of tin corresponding closely to the formula Sn_4Zn, which would call for 70.7 per cent. The solder as now made contains 1 part aluminium, 1 part phosphor tin, 11 parts zinc and 29 parts tin, giving it 71.2 per cent. of tin. The solder fuses easily at a heat attainable with a copper or nickel bolt, and possesses great ability to take hold on the metal. It is so tough that if a joint is well made the metal will break before the solder. It is very nearly the color of aluminium, but darkens slightly on standing some time; when the article is in constant wear, however, the solder retains its bright color; when discolored it becomes bright

* United States patent, 478,238, July 5, 1892; English patent, 20,208, 1892.

again by polishing. The edges to be joined are filed or scraped clean immediately before soldering, then, if the piece will allow, heated to a temperature at which the solder melts, and the edges are tinned by rubbing with a stick of solder. If the whole piece cannot be heated, the edges can be tinned by heating with a tinned bolt and rubbing in the melted solder briskly. Any surplus solder is removed from the edges by a small scraper, while still hot. The prepared edges are then soldered together in any way desired. For a lap-joint, the edges are overlapped, the soldering bolt passed along, and a little extra solder melted in the joint. For a joint at an angle, it is necessary that the bolt be shaped to fit, as the solder must be rubbed in well at the edges. No flux of any kind is to be used either on the bolt or on the joint. In making a lock seam, the edges of the aluminium should be coated with the solder as above-described before being turned over, else the solder cannot soak into the joint. Common sheet-tin does not need such preparation, because the whole sheet is already tinned to start with. In brief, aluminium is similar to copper and black-iron, not like tinned iron, and the edges must be prepared for soldering.

CHAPTER XII.

LEAD ALLOYS.

Lead in a pure state is but little used except for pipes, foil, and for certain chemical purposes. Some of its alloys, however, are of great importance, and are generally used, notwithstanding many efforts to replace them, especially for typographical purposes. An addition of other metals generally makes the lead harder and more or less injures its ductility. An addition of copper imparts to the alloy greater hardness without impairing its ductility to a serious extent, and if the content of copper be small such an alloy can be drawn to pipes or rolled out to thin sheet.

A content of arsenic, antimony, and tin increases the hardness of lead, but considerably impairs its ductility. Antimony and arsenic especially exert a strong influence in this respect, while the lead-tin alloys retain their ductility. Lead-antimony alloys containing less than 22 per cent. antimony contract on cooling and are therefore not suitable for sharp castings; only mixtures richer in antimony expand on cooling and reproduce the finest depressions of the mould. The hardness of lead-antimony alloys increases with the content of antimony, alloys with 11 to 17 per cent. antimony being about four times as hard as lead, and alloys with 23.5 per cent. antimony five times. A larger content of antimony makes the alloys still harder (with over 25 per cent. twelve times as hard as lead), but on account of their brittleness they are not suitable for technical purposes. The affinity of zinc and iron for lead being very small it is difficult to prepare alloys with them. The most important alloys of lead are type-metal and shot-metal, the

first generally an alloy of lead with antimony, and the latter, one with arsenic.

Type-Metal.

An alloy to serve for type-metal must allow of being readily cast, fill the moulds sharply, and at the same time be as hard as possible. Though it is difficult entirely to satisfy these demands, an alloy consisting of lead and antimony answers the purpose best. Antimony increases the hardness of lead and renders it very brittle if present in too large a proportion. An alloy of lead 76 parts, and antimony 24, appears to be the point of saturation of the two metals. More fusible than the average fusibility of the two component metals, ductile and considerably harder than lead, this alloy expands in cooling, and to this property is due its employment for the manufacture of type. But the above compound does not answer perfectly well, especially for small type. When too soft it gets out of shape, when too hard it cuts the paper; and it happens very often that the founder goes to one or the other extreme. When the alloy is melted in contact with the air antimony is oxidized much more rapidly than lead, and this accounts for the difficulty of obtaining an exact composition. It is a constant subject of study for type-founders to arrive at a fusible and homogeneous metal with much expansion, resistant as much as possible, and, at the same time, soft enough to be repaired and to bear the action of the press without being soon put out of shape.

The alloy of equal proportions is porous, and brittle. These defects increase in the same ratio as the proportion of antimony increases. On the other hand they disappear when the lead takes the place of antimony. An alloy of lead 4 parts and antimony 1 is compact, much harder than lead, and remains malleable.

An alloy of antimony 1 part and lead 8 is very tough, and has a higher specific gravity than the proportional

specific gravity of the two metals. It is more malleable than the preceding alloy and retains a certain degree of hardness. The hardness imparted by antimony, the increase in toughness, and that in the specific gravity are quite perceptible in alloys of antimony 1 part and lead up to 16 parts.

At present a great many receipts for type metal are known, in the preparation of which other metals besides lead and antimony are used for the purpose of rendering the alloy more fusible (additions of bismuth as imparting to them greater power of resistance, as well as copper and iron having been recommended for the purpose). By such admixtures the fusibility of the alloys is, however, impaired, and the manufacture of the types becomes much more difficult than with an alloy of lead and antimony alone. In the following table some alloys suitable for casting type are given:

Metals	Parts.									
	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.
Lead	3	5	10	10	70	60	55	55	100	6
Antimony	1	1	1	2	18	20	25	30	30	—
Copper	—	—	—	—	2	—	—	—	8	4
Bismuth	—	—	—	1	—	—	—	—	2	—
Zinc	—	—	—	—	—	—	—	—	—	90
Tin	—	—	—	—	10	20	20	15	20	—
Nickel	—	—	—	—	—	—	—	—	8	—

French and English type-metals always contain a certain quantity of tin, as shown by the following analysis:

	English types.			French types.
Lead	69.2	61.3	55.0	55
Antimony	19.5	18.8	22.7	30
Tin	9.1	20.2	22.1	15
Copper	1.7	—	—	—
	99.5	100.3	99.8	100

According to Ledebur, type-metal contains:—

Lead	75	60	80	82
Antimony	23	25	20	14.8
Tin	2	15	—	3.2

I. Ordinary; II. fine quality of type-metal; III. alloy for sticks; IV. for stereotype plates.

Erhart's type metal.—Erhart recommends the following alloys as being hard and at the same time ductile: Zinc 89 to 93, tin 9 to 6, lead 2 to 4, copper 2 to 4.

The tin is first melted and then the lead and zinc are added in succession, and finally the copper.

The manufacture of the type from the alloys is seldom effected by cold stamping in steel moulds, the process being very expensive; hence they are generally cast. According to the old process the types are cast piece by piece by means of a small casting ladle, but for types with a large face and much detail, the motion of the hand is barely sufficient to give the momentum required to throw the metal into the matrix and produce a clean, sharp impression. A machine is then used, which may be compared to a small forcing-pump, by which the mould is filled with the fluid metal; but from the greater difficulty of allowing the air to escape, such types are in general considerably more unsound in the shaft or body, so that an equal bulk of them only weighs about three-fourths as much as type cast in the ordinary way by hand, and which for general purposes is preferable and more economical.

Some other variations are resorted to in type-founding; sometimes the mould is filled twice, at other times the faces of the types are *dabbed* (the *cliché* process), many of the large types and ornaments are stereotyped and either soldered to metal bodies or fixed by nails to wooden blocks. The music type and ornamental borders and dashes display much curious power of combination. *Plates for engraving music* are generally made of tin 5 to 7.5 parts, antimony 5 to 2.5.

Type-metal being easily cast may also be used for candlesticks, statuettes, etc., sand moulds being generally employed for the purpose, though for decorated articles metallic moulds thoroughly rubbed inside with oil can be advantageously used.

An alloy for keys of flutes and similar parts of instruments consists of lead 2 parts, antimony 1.

Shot-Metal.

The mixture of metal used for the manufacture of shot consists of lead and arsenic. The latter, as previously mentioned, possesses the property of hardening lead, the alloy being at the same time more fusible than pure lead. Shot, as is well known, is prepared by letting fall from an elevated place drops of lead into water, and an addition of a very small quantity of arsenic to the lead helps its solidification and gives to the shot a more spherical shape.

On account of the poisonous properties of the arsenious vapors certain precautions have to be preserved in preparing the alloy. In a cast-iron pot provided with a well-fitting lid, the lead is first melted and then covered with a layer of charcoal dust. Only after this is done should the arsenic or arsenious combination to be used be introduced. In many shot-factories this precaution is omitted, which, however, deserves censure, as everything should be done to protect the workmen from the injurious effects of the poisonous arsenious vapors. If the metal is covered with a layer of charcoal dust, the vapors cannot reach the air as easily as when the bright metal is in direct contact with the air. White arsenic (arsenious acid) is generally used as an addition to the lead, though in some cases red arsenic (realgar or red orpiment) is employed. Immediately after the introduction of the arsenic the mass is vigorously stirred with a wooden rod, and the pot is then covered with the lid, which is luted around the edges with moist clay.

A strong fire is now kept up to render the contents of

the pot thinly-fluid. After about three hours the lid is removed and the charcoal and oxides floating upon the surface having been carefully lifted off, the alloy is poured with ladles into moulds. This alloy serves for the preparation of the actual shot-lead, which is prepared by melting lead and adding a certain quantity of the alloy of lead and arsenic. It is in all cases preferable first to prepare the arsenious alloy in the manner prescribed, it being otherwise difficult intimately and homogeneously to combine the lead with the comparatively small quantity of arsenic required for shot-metal.

In working by the preceding process generally 1000 parts of lead are alloyed with 20 of arsenic, and equal parts of this alloy and of lead are subsequently melted together. For the direct preparation of the alloy of lead and arsenic for shot, 2.4 parts of arsenious acid are used for 600 parts of refined lead, or 3.0 parts of arsenic to 700 parts of lead. As will be seen the quantity of arsenic is exceedingly small, and should in no case exceed that actually required for hardening the lead and rendering it easy to cast. The quantity considered necessary for this varies much in different countries. While, for instance, in England 10 parts of arsenic are allowed for 1100 parts of lead, in France 3 to 8 parts are considered sufficient for 1000 parts of lead.

This variation in the proportions of arsenic used for hardening the lead is readily accounted for by the difference in the qualities of the lead used; the purer and softer the lead the greater the quantity of arsenic required. But under no circumstances should good shot-metal contain more than from $\frac{1}{1000}$ to $\frac{10}{1000}$ of the weight of lead used.

Both a too small or too large content of arsenic is injurious; if the lead contains too little arsenic, the resulting shot has the shape of tears, and the interior is frequently full of cavities, while with too much arsenic the drops are lenticular. As even with much experience it is quite difficult to hit at once the right proportion, it is advisable, be-

fore melting together large quantities of lead and arsenic, first to make tests with small quantities. From the shape of the shot obtained from these samples it can be readily judged whether the proportions are right or in what respect they have to be changed.

Many manufacturers of shot, it would seem, vary the composition of the alloys used by them, for, besides lead and arsenic, other metals are frequently found in shot, especially antimony and copper, though the latter only in exceedingly small quantities. The content of antimony is, however, larger, reaching in many cases 2 per cent. of the total weight, and from this it would appear that the manufacturers endeavor to replace the arsenic by antimony.

Casting of shot.—According to the old method, shot is prepared by allowing the melted metal to fall in drops from a tower of considerable height. This method is said to have originated with a plumber of Bristol, England, named Watts, who, about the year 1782, dreamed that he was out in a shower of rain, that the clouds rained lead instead of water, and the drops of lead were perfectly spherical. He determined to try the experiment, and, accordingly, poured some melted lead from the tower of St. Mary Redcliffe Church into some water below; the plan succeeded, and he sold the invention for a large sum of money.

For carrying out this invention shot-towers and shot-wells have been constructed. At the top of the tower melted lead is poured into a colander and the drops are received into a vessel of water below. The surface of the lead becomes covered with a spongy crust of oxide called *cream*, which is used to coat over the bottom of the colander to prevent the lead from running too rapidly through the holes, whereby they would form oblong spheroids instead of spheres. The colanders are hollow hemispheres of sheet-iron, the holes in them differing according to the size of the shot. They must be at a distance of at least three times the diameter of the shot from each other, as

otherwise it might happen that two or more drops of lead would while falling down, unite to one mass, which, of course, would be useless and have to be remelted.

The water serving for the reception of the drops must be frequently changed to prevent it from becoming too hot or boiling. By some it is recommended to pour a layer of oil upon the surface of the water, the shot retaining thereby its spherical shape better than when dropping directly into the water. To prevent the shot, when taken from the water, from losing its metallic appearance by oxidation, a small quantity, (about 0.25 per cent.) of sodium sulphide is dissolved in the water serving for the reception of the shot, by means of which the drops falling into it are at once coated with a thin film of sulphide of lead of a lustrous, metallic, gray-black color, which is permanent even in moist air.

In more recent times the formation of shot by centrifugal power has been introduced, which does away with the expensive towers. The melted lead is poured in a thin stream upon a rapidly revolving metal disk, surrounded at some distance by a screen against which the shot is thrown. The moment the melted lead falls upon the metal disk it is divided by the centrifugal force into drops, the size of which depends on the rapidity with which the disk revolves. The drops are hurled in a tangible direction from the disk and are stopped by the above-mentioned screen.

David Smith, of New York, has invented and put into practice a mode of manufacturing drop-shot. The chief feature of this invention consists in causing the fused metal to fall through an ascending current of air, which shall travel at such a velocity that the dropping metal shall come in contact with more particles of air in a short tower than it would in falling through the highest towers before in use. Fig. 33 is a vertical sectional elevation of a sheet-metal cylinder set up as a tower within a building, and may be about 20 inches internal diameter and 50 feet high or

less. This tower, although mentioned in Smith's patent, is now dispensed with in the middle of the height, so that only an open space remains. Fig. 34 is a plan at the line *a b;* Fig 35 is a plan at the line *q r:* Fig. 36 is a section at *o p;* and Fig. 37 is a section at *m n*, Fig. 33.

FIG. 33.

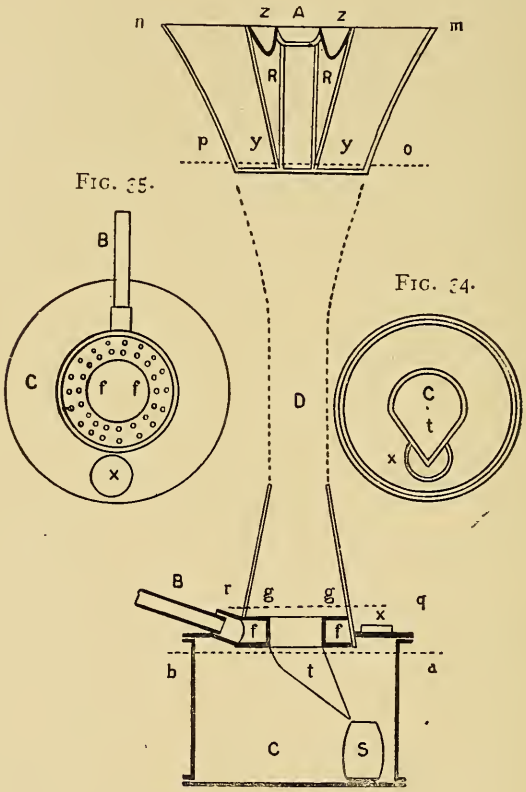


FIG. 35.

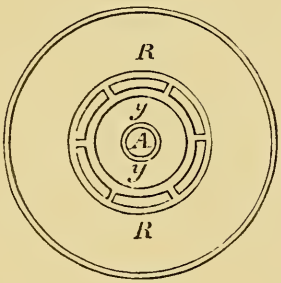
FIG. 34.

C is a water cistern beneath the tower. *B* is a pipe from the blowing apparatus leading into the annular chamber *f;* the upper surface *g* is perforated as shown in Fig. 35 to disperse the ascending air. The outer side of this annular ring *f* forms the base of a frustrum of a cone, forming the

tower *D*, passing the blast through the frame *yy*, Fig. 36; and in Fig. 37 is shown to support a cylindrical standard *R*, the upper central portion of which receives the pouring pan *A*. This pan is charged with each separate size of shot. Round the pouring pan *A* is a circular waste trough *z*. The object of this arrangement is that the fluid metal running through the pouring-pan *A* into the ascending current of air, will be operated upon in the same manner as if it fell through stagnant air of great height. The shot falls

FIG. 36.

FIG. 37.



through the open center of the ring *f* into the water cistern *C*, where a chute *t* carries it into the tub *S*, which when full may be removed through *x*, an aperture in the cover of the cistern.

Sorting the shot.—Even with the most careful work it happens that drops of unequal size or cornered masses are found among the shot, and the latter, after being taken from the water and dried, must be sorted. This was formerly effected by hand in the following manner: A slab of polished iron is tilted at a certain angle, and the shot are strewed along the upper part of the inclined plane thus formed. The perfect shot proceed rapidly in straight lines and fall into a bin placed to receive them, about a foot away from the bottom of the slab. The misshapen shot, on the contrary, travel with a slower zigzag motion and fall without any bound into a bin placed immediately at the

end of the incline. The perfect shot are then subjected to another sorting by passing them through sieves with meshes of exactly the same size as the apertures in the casting colanders.

The finished shot, which are now of dead silvery-white color are polished and made dark in an iron barrel or *rumble* containing a quantity of powdered plumbago. They are then tied up in canvas bags and are ready for sale.

At present the shot are, however generally sorted by means of sorting drums consisting of inclined cylinders perforated with holes whose diameter corresponds to that of the shot. The forward motion of the shot in these drums is effected by means of an Archimedean screw.

Large shot are at the present time also frequently prepared by casting in moulds like bullets, or by stamping them from thin plates of the alloy. In both cases the resulting shot shows a seam which is removed by bringing the shot together with very fine quartz sand into revolving drums. By the action of the sand the seams are ground off, and a perfectly spherical shape imparted to the shot.

Alloys of lead and iron.—Lead, as previously stated, has no affinity for iron. A piece of lead thrown into a bath of melted iron becomes oxidized, or is separated and found at the bottom of the bath after the cast-iron has been run out. As soon as the lead is introduced into the melted cast-iron, a certain agitation appears on the surface, and even through the whole bath, and the cast-iron seems more fluid. When thin or large pieces are to be cast, the founders, who are aware of this phenomenon, often throw a certain quantity of lead into the melted cast-iron in order to prevent it from congealing too soon against the sides of the casting ladle.

This want of affinity of lead for iron, and conversely, is made use of for separating iron from other metals, such as silver, for instance. Thus if lead is added in sufficient quantity to a fused alloy of cast-iron and silver, it will combine with the silver, and the iron will float on the surface of the bath.

All the authors who have occupied themselves with the question of alloys agree upon the impossibility of alloying lead and iron.

Alloys of lead and other metals.—Lead, as seen from the preceding sections, is much used in the preparation of alloys which have been already partially mentioned under the respective mixtures of metals. Lead is also frequently alloyed with cadmium and bismuth, and forms an important constituent of the so-called soft-solder. In speaking of these compounds, the lead alloys not yet mentioned will be referred to. Only type-metal and shot-metal can be considered as lead alloys, *i. e.*, alloys of which lead forms the greater portion.

CHAPTER XIII.

CADMIUM ALLOYS.

Cadmium shares with bismuth the property of considerably lowering the melting points of alloys, but while the bismuth alloys are nearly all brittle, many alloys of cadmium possess considerable ductility, and can be worked under the hammer as well as between rolls. They act, however, very differently in this respect, there being alloys which are very ductile, and others again, though containing in addition to cadmium the same metals only in different proportions, which are very brittle.

An alloy consisting, for instance, of cadmium and silver, shows this phenomenon in the most remarkable manner. By melting together one part of cadmium and one to two parts of silver a very ductile alloy is obtained which can be rolled out to a very thin sheet. By taking, however, two parts of cadmium to one of silver, the resulting alloy is so brittle as to break into pieces under the hammer.

As cadmium imparts to the alloys a very low melting point, it is frequently used in the preparation of very fusible solders, for casting articles not to be exposed to a high temperature, and, in denistry, for compounds for filling hollow teeth.

Alloys of cadmium contain generally tin, lead, bismuth, and sometimes mercury, the latter being chiefly added to lower the melting point still more. Alloys of cadmium and mercury alone (cadmium amalgams) are solid and malleable, hence the addition of mercury does not impair their solidity.

Lipowitz's alloy.—This alloy is composed of cadmium 3

parts, tin 4, bismuth 15, lead 8. It is best prepared by heating the comminuted metals in a crucible and stirring, as soon as fusion begins, with a stick of hard wood. This stirring is of importance in order to prevent the metals, whose specific gravity varies considerably, from depositing themselves in layers. This alloy softens at 140° F., and melts completely at 158° F.

Lipowitz's metal has a silvery-white color, a luster like polished silver, and can be bent short, hammered, and worked in the lathe. It, therefore, possesses properties adapting it for many purposes where a beautiful appearance is of special importance, but on account of the considerable content of cadmium and bismuth, the alloy is rather expensive and finds but limited application. Castings of small animals, insects, lizards, etc., have been prepared with it, which in regard to sharpness were equal to the best galvano-plastic products. Plaster of Paris is poured over the animal to be cast, and after sharply drying, the whole animal is withrawn from the mould and the latter filled up with Lipowitz's metal. The mould is then placed in a vessel containing water, and by heating the latter to the boiling point the metal is melted and deposits itself in the finest impressions of the mould.

The alloy is very suitable for soldering tin, lead, etc., and on account of its silver-white color is especially adapted for soldering Britannia metal and nickel. But the costliness of the alloy prevents its general use for this purpose, and cheaper alloys having nearly the same properties as Lipowitz's metal have been prepared.

Cadmium alloy (*melting point* 170° F.)—Cadmium 2 parts, tin 3, lead 11, bismuth 16.

Cadmium alloy (*melting-point* 167° F.).—Cadmium 10 parts, tin 3, lead 8, bismuth 8.

Cadmium alloy (*melting-point* 203° F.).—The following compositions have all the same melting-point (203° F.).

	Parts.		
	I.	II.	III.
Cadmium	1	1	1
Tin	2	3	1
Bismuth	3	5	2

Very fusible alloy.—An alloy with a melting point of 150° F. is composed of:—

	Parts.		
Tin	1	or	4
Lead	2	or	3
Bismuth	4	or	15
Cadmium	1	or	3

Wood's alloy or metal melts between 140° and 161.5° F. It is composed of lead 4 parts, tin 2, bismuth 5 to 8, cadmium 1 to 2. In color it resembles platinum, and is malleable to a certain extent.

Cadmium alloy (*melting-point* 179.5° F.).—Cadmium 1 part, lead 6, bismuth 7. This alloy, like the preceding, can be used for soldering in hot water.

Cadmium alloy (*melting-point* 300° F.).—Cadmium 2 parts, tin 4, lead 2. This alloy yields an excellent soft solder, with a melting-point of about 86° below that consisting of lead and tin alone.

Cliché metal.—An alloy consisting of lead 50 parts, tin 36, and cadmium 22½, is especially adapted for the preparation of clichés, since with as low a melting-point as the cliché metals (of bismuth alloys) generally used, it combining the valuable property of greater hardness. With a cliché of this alloy, a large number of sharp impressions are obtained.

According to Hauer, the melting-points of fusible alloys are proportionate to the atomic composition, thus:

Formula.	Melting point.
1. $CdSnPbBi$.	155.1° F.
2. $Cd_2Sn_1Pb_1Bi_2$.	153.5° "
3. $Cd_4Sn_1Pb_3Bi_5$.	150.0° "
4. $CdPb_6Bi_7$.	190.4° "
5. $CdPb_3Bi_2$.	193.0° "
6. $Cd_2Pb_7Bi_4$.	203.0° "

The above formulas correspond to the following percentage compositions :—

Cadmium	17.31	13.6	14.3	4.0	9.7	8.9
Tin	18.24	19.0	16.0	—	—	—
Lead	32.00	33.4	33.1	44.0	54.0	57.7
Bismuth	32.45	34.0	36.6	52.0	36.3	33.4

It is sometimes claimed that cadmium alloys are not constant as to their melting-points, and that on account of the volatility of cadmium, the alloy will fuse with greater difficulty the oftener it is remelted. A glance at the above figures shows plainly that cadmium cannot volatilize at these temperatures, and, further, a series of experiments made especially for the purpose, has shown that the alloys can be melted as often as desired without their melting points being sensibly changed. It may, however, happen that the alloys, originally homogeneous, may by liquation separate into several alloys with different melting-points, if a large quantity of it be allowed to stand in a melted state for a long time. This can, however, be readily prevented by not keeping the alloy in a liquid state until this liquation takes place, which requires many hours, and if it does take place, by vigorous stirring of the melted alloy.

The alloys of cadmium with mercury (cadmium amalgams), will be referred to in speaking of amalgams, and those containing gold, which are for certain purposes used by gold workers, will be mentioned under gold alloys.

CHAPTER XIV.

BISMUTH ALLOYS.

LIKE cadmium, bismuth possesses the property of lowering the melting points of metals, and is, therefore, frequently used in the preparation of fusible alloys, which would be still more extensively used if bismuth could be obtained in abundance and at a small cost. The alloys are now chiefly used in the preparation of delicate clichés, very fusible solders, and in the manufacture of safety-valves of a peculiar construction for steam boilers.

The behavior of bismuth towards other useful metals is given by Guettier as follows:—

Alloys of bismuth and copper.—These alloys are easily effected notwithstanding the difference in the points of fusion of the two metals. They are brittle and of a pale-red color whatever the proportions employed. Their specific gravity is sensibly equal to the average of the two metals.

Alloys of bismuth and zinc.—These alloys are seldom made and produce a metal more brittle, presenting a large crystallization with less adherence than zinc or bismuth taken singly. On that account they are useless in the arts.

Alloys of bismuth and tin.—The combinations of bismuth and tin take place easily and in all proportions. A very small quantity of bismuth imparts to tin more hardness, sonorousness, luster and fusibility. On that account and for certain applications a little bismuth is added to tin to increase its hardness, However, bismuth being easily oxidized and often containing arsenic, the alloys of tin and bismuth would be dangerous for the manufacture of domestic utensils such as culinary vessels, pots, etc.

The alloys of tin and bismuth are more fusible than each of the metals taken separately. An alloy of equal parts of

the two metals is fusible between 212° and 302° F. When tin is alloyed with as little as 5 per cent. of bismuth, its oxide acquires the peculiar yellowish-gray color of the bismuth oxide. According to Rudberg, melted bismuth begins to solidify at 507° F., and tin at 550° F. For the alloys of the two metals the "constant point" is 289° F.

Alloys of bismuth and lead.—These two metals are immediately alloyed by simple fusion with merely the ordinary precautions. The alloys are malleable and ductile as long as the proportion of bismuth does not exceed that of lead. Their fracture is lamellar, and their specific gravity greater than the mean specific gravity of either metal taken singly. An alloy of equal parts of bismuth and lead has a specific gravity equal to 10.71. It is white, lustrous, sensibly harder than lead, and more malleable. The ductility and malleability diminish with an increased proportion of bismuth, while they increase with the excess of lead in the alloy. An alloy of bismuth 1 part and lead 2 is very ductile, and may be laminated into thin sheets without cracks. According to Berthier, its point of fusion is 331° F.

Alloys of bismuth and iron.—Authorities disagree as to the possibility of combining bismuth and iron. The presence of bismuth in iron renders the metal btittle.

It will be seen, from the preceding data, that the alloys of bismuth are not at present of importance in the arts excepting the fusible alloys made of bismuth and certain white metals, such as tin, lead etc., and a few others.

Alloys of bismuth with antimony.—The alloys of these two metals alone are grayish, britle, and lamellar. In order to remove the brittleness, varying quantities of tin and lead are added, whereby their fusibility rather increases than decreases. Alloys containing the above metals are much used in the preparation of Britannia and Queen's metals, but they are also employed for some special purposes of which the following are examples:

Cliché metal.—This alloy is composed of tin 48 parts,

lead 32.5, bismuth 9, and antimony 10.5. It is especially suitable for *dabbing* rollers for printing cotton goods, and, possessing a considerable degree of hardness, it wears well.

For filling out defective places in metallic castings, the following alloy can be used to advantage: Bismuth 1 part, antimony 3, lead 8.

Alloys of bismuth, tin, and lead.—The compounds obtained by alloying these metals have a somewhat higher melting point than the cadmium alloys. They have, however, been known for a long time, and are used for various purposes.

Newton's metal consists of bismuth 8 parts, lead 5, tin 3. It melts at 202° F.

Rose's alloys consist of:—

	I.	II.
Bismuth	2	8
Tin	1	3
Lead	1	8

Parts.

The first of these alloys melts at 200.75° F., and the other at 174.20 F. These alloys were formerly used in the preparation of the so-called safety-plates which were inserted in the tops of steam boilers. The composition of these plates was such that they became fluid at a determined temperature corresponding to a certain steam pressure in the interior of the boiler, thus giving the steam a chance to escape through the aperture formed. Such plates acted as a sort of safety-valve, and were intended to prevent the explosion of the boiler with too high a tension of steam.

At the present time their use has, however, been almost entirely abandoned, it having been found that boilers provided with these plates would explode, without a previous melting of the plates. A chemical and physical examination has shown that, by long-continued heating of the plates, alloys are formed whose melting points are much higher than those of the compositions originally used. The following table gives the compositions of some alloys which are said to melt, if the pressure of the steam exceeds that indicated:—

Bismuth.	Lead.	Tin.	Melting point. Degrees F.	Corresponding pressure of steam in atmosphere.
8	5	3	212	1
8	8	4	235.9	1½
8	8	8	253.9	2
8	10	8	266	2½
8	12	8	270.3	3
8	16	14	289.5	3½
8	16	12	300.6	4
8	22	24	308.8	5
8	32	36	320.3	6
8	32	28	331.7	7
8	30	24	341.6	8

Onion's fusible alloy consists of lead 3 parts, tin 2, bismuth 5. It melts at 197° F.

D'Arcet's fusible alloys. Mr. D'Arcet gives the following proportions for fusible alloys:—

No.	Parts.			Remarks.
	Bismuth.	Lead.	Tin.	
1	7	2	4	Softens at 212° F., without melting.
2	8	2	6	Softens at 212° F., easily oxidized.
3	8	2	4	Softens more or less at 212° F. No. 4 becoming softer than either No. 3 or No. 5.
4	16	4	7	
5	9	2	4	
6	16	5	7	Becomes nearly fluid at 212° F.
7	8	3	4	Becomes quite liquid at 212° F.
8	8	4	4	Becomes very liquid at 212° F.
9	8	7	1	Becomes soft at 212° F., but does not melt.
10	16	15	1	Neither liquid nor soft at 212° F.
11	8	5	3	Melts at 205° F.
12	8	6	2	Melts at 205° F.
13	16	9	7	Becomes very liquid at 212° F.

These alloys are generally hard, but may be cut. Their fracture is a dead blackish-gray. They are rapidly tarnished in the air, and more so in boiling water, in which they become covered with a wrinkled pellicle which falls as a black powder.

Lichtenberg's metal.—Bismuth 5 parts, lead 3, tin 2. Melts at 197° F.

Bismuth alloys for delicate castings.—For the preparation of castings of delicate articles, and taking impressions from dies, medals, etc., bismuth alloys of the following compositions have been recommended :—

	Parts.			
	I.	II.	III.	IV.
Bismuth	6	5	2	8
Tin	3	2	1	3
Lead	13	3	1	5

On cooling, these alloys expand strongly, and, consequently, fill out the finest depressions and elevations.

Bismuth alloy for cementing glass.—Most cements in use are dissolved by petroleum, or, at least, softened. The following alloy, which melts at 212° F., is, however, not attacked by petroleum, and is therefore well adapted for fastening the metal parts upon glass lamps: Lead 3 parts, tin 2, bismuth 2.5.

The following table, made by Messrs. Parkes and Martin, indicates the various points of fusion of the fusible combinations of bismuth, lead, and tin :—

Parts.			Temperature of fusion. Degrees F.	Parts.			Temperature of fusion. Degrees F.
Bismuth.	Lead.	Tin.		Bismuth.	Lead.	Tin.	
8	5	3	202°	8	16	24	316°
8	6	3	208	8	18	24	312
8	8	3	226	8	20	24	310
8	8	4	236	8	22	24	308
8	8	6	243	8	24	24	310
8	8	8	254	8	26	24	320
8	10	8	266	8	28	24	330
8	12	8	270	8	30	24	342
8	16	8	300	8	32	24	352
8	16	10	304	8	32	28	332
8	16	12	294	8	32	30	328
8	16	14	290	8	32	32	320
8	16	16	292	8	32	34	318
8	16	18	298	8	32	36	320
8	16	20	304	8	32	38	322
8	16	22	312	8	32	40	324

These alloys are valuable baths for tempering small steel tools. They give a very exact temperature, which may be adjusted to the purpose intended. They are used, according to Thurston,* by placing the article on the surface of the unmelted alloy and gradually heating until fusion occurs and they fall below the surface, at which moment their temperature is right; they are then removed and quickly cooled in water. It is not easy, even if possible at all, to give as uniform a temperature by the ordinary processes of heating or to obtain the exact heat desired, and the quality of the tool is not so easy of adjustment by any other method.

Alloys of lead and bismuth have also been tried. They are too easily oxidized, and are difficult to make on account of the separation of the lead. An alloy of equal parts of bismuth and lead possesses a toughness from fifteen to twenty times that of lead.

Alloys of bismuth and tin succeed better; those which are best known are—

Bismuth.	Tin.	Melts at about.
50 parts.	50 parts	310° F.
33 "	67 "	325
20 "	80 "	480

The first alloy (equal parts of bismuth and tin) is called *cutlanego*, and the oxide of it makes a white enamel.

Very fusible alloy. This alloy which is suitable for many applications in the arts is composed of bismuth 48 parts, cadmium 13, lead 19, tin 26. It melts at about 158° F., and, consequently, at a lower temperature than that at which the so-called "magic spoon" melts in a cup of tea. It is said to resist great pressure.

* Brasses, Bronzes and other Alloys, p. 196.

CHAPTER XV.

IRON-ALLOYS (ALLOY STEELS.)

The substances which combine with iron, and alloy with it, are derived either from the raw materials—ores, fluxes, reducing material—in short the charge used in the manufacture of the iron, and are therefore unavoidable and frequently troublesome associates of the latter, or they are intentionally added in definite quantities in order to produce an iron-alloy suitable for certain industrial purposes.

In the first case it is scarcely possible to regulate as much as would be desirable the quantity of the constituents, and thereby, their influence upon the properties of the iron. Thus, copper, sulphur and phosphorus are to a certain extent associates of commercial iron manufactured on a large scale and cannot be removed, they remaining as troublesome admixtures, and relatively small quantities of them may impair the value of the iron for certain applications.

Hence iron as found in commerce may be considered more or less of an alloy. Perfectly pure iron which can be electro-chemically prepared at great expense is not worked at all. The relatively purest iron which can be made by smelting processes on a large scale, contains about 99.6 per cent. of iron and 0.4 per cent. of other constituents, chiefly carbon and secondarily, phosphorus, sulphur, copper, manganese, silicon. The color of such iron is pale gray, its tensile strength in pieces of larger cross-sections is about 30 kilogrammes per square millimeter, and considerably more with smaller cross-sections. It is furthermore very tenacious, has a specific gravity of 7.8, and melts at about 2732° F. The most important, never

wanting constituent of iron is carbon; it is derived from the reducing material of the charge and exerts a peculiar influence upon the properties of iron. However, there is a limit to the capacity of iron of alloying with carbon, the greatest amount of carbon which pure iron can absorb being about 4 to 4.5 per cent.; iron with the largest content of carbon melts at about 1922° F. Iron with about 1 per cent. carbon possesses the greatest tensile strength, but its tenacity is not very great. With an increase in the content of carbon, the tensile strength decreases and brittleness increases.

The content of carbon serves as a distinctive mark of the different varieties of iron. Iron with less than 2.6 per cent. carbon is called *malleable iron*, and with more than 2.6 per cent., *pig iron*, the former containing as a rule less than 1.5 per cent., and the latter over 3 per cent. The malleable varieties of iron with more than 0.5 per cent. carbon are distinguished by special hardness and strength, and are called *steel*, while those poorer in carbon are softer and not so strong, but more tenacious, are termed *wrought iron*. However, this classification according to the content of carbon cannot always be carried out, other points regarding the differences in the above-mentioned varieties of iron having to be taken into consideration.

Another admixture which frequently occurs, besides carbon, is silicon. It is derived from the raw material used for the production of the iron; in malleable iron it does not exceed 1 per cent., and in pig iron to be used for industrial purposes, not 3 per cent. A comparatively large content of silicon causes in pig iron rich in carbon, when cooling, a separation of carbon in the form of graphite, more of the latter being separated in slow, and less in rapid, cooling. However, in any case, the iron, by this separation of carbon in the form of graphite, acquires essentially other properties. Pig iron rich in graphite is less brittle and hard, and is called *gray pig iron* or *foundry pig*, while pig iron free

from graphite is very hard and brittle, has a silver-white fracture and is called *white pig iron*. With only a moderate content of carbon and a comparatively small content of silicon—about 3.5 per cent. carbon and 0.8 to 1 per cent. silicon—the separation of graphite can be entirely prevented by rapid cooling; the production of chill castings is based upon this possibility. Iron-silicon alloys with up to 20 per cent. silicon are sometimes intentionally produced. They are, however, not directly worked into articles of use but serve for certain purposes in iron works.

The manganese which also occurs in iron, is, as a rule, not intentionally added, but is reduced in smelting from manganiferous iron ores and absorbed by the iron. In malleable iron the content of manganese amounts generally to 1 per cent., and in foundry pig to about 1.5 per cent. A larger content of manganese in these varieties of iron would increase their hardness and brittleness, and exert an injurious influence upon their capacity of being worked.

For special purposes iron is sometimes alloyed with up to 14 per cent. of manganese in order to produce the so-called *manganese-steel*, which is distinguished by great hardness.

Ferro-manganese with up to 85 per cent. of manganese is intentionally produced to be used as addition in iron works, especially in the manufacture of mild steel.

The ferro-manganese is usually added to the melted steel after it is tapped into the ladle. For ordinary steels the ferro-manganese is used for the removal of oxygen from the metal, so that a considerable proportion of the manganese finds its way into the slag leaving only 0.5 to 1 per cent. of manganese in the finished steel. This quantity seems to have almsot no influence on the physical properties of the steel except to counteract the tendency to red-shortness; but as the percentage of manganese approaches 3 per cent. an excessive brittleness shows itself, rendering the metal almost useless; and when 5 to 6 per cent. is reached,

the steel is so hard and brittle that it can readily be powdered by crushing. However, when 7 per cent. of manganese is exceeded an extraordinary change takes place immediately, and with from 8 to 20 per cent. manganese an alloy known as *Hadfield's manganese steel* is obtained, which possesses remarkable characteristics. An excellent quality of razors and axes have been made from Hadfield steel containing 13.75 per cent. manganese and 0.85 per cent. of carbon. This alloy, after forging and water-toughening gave, on testing, a tensile strength of 65 tons per square inch, and almost 51 per cent. elongation.

The use of manganese steel is likely to be restricted on account of the difficulty of machining and filing it, but it can be partially softened by treatment in the following manner: The tool is heated to very little over 1832° F., and suddenly quenched in cold water nearly at the freezing point, when the metal becomes soft enough to be easily filed or even planed. To restore the former hardness, heating to a bright red heat (say 1382° F.) and slowly cooling in the air is sufficient.

The main use of manganese steel is confined to purposes where extreme hardness is necessary, such as the working faces of crushing mills and grinding machinery. Car wheels, also railway crossings are frequently made of this alloy.*

Chrome-steel.—According to the investigations of Berthier, Frémy, Smith and others, iron and chromium unite in all proportions by strongly heating a mixture of the oxides of iron and chromium in brasqued crucibles, adding powdered charcoal if the oxide of chromium is in excess, and fluxes to scorify the earthy matter and prevent oxidation. According to Howe,† this is substantially the same method for preparing ferro-chrome as employed at Brooklyn, New

*Greenwood "Steel and Iron."

†Metallurgy of Steel, p. 75.

York, and Unieux Works in France, where chrome-steel has been produced in large quantities for a number of years. According to the method of Guétat and Chavanne* a neutral solution of potassium calcium chromate or of sodium calcium chromate is mixed with an equivalent quantity of ferrous chloride, the precipitate of ferric chromate washed, roasted, mixed with a sufficient quantity of coal dust, and heated to a white heat in a well-luted crucible, in which the ferro-chrome fuses together to a regulus.

The ferro-chrome from Kapfenberg in Styria contains, according to Schneider, 44.5 per cent. chromium and 48.2 per cent. iron, besides fixed carbon. From this and similar alloys the iron may be extracted with dilute hydrochloric acid, or with chloride of copper, whereby acicular crystals of the composition $Fe_4C.Cr_{12}C_4$ remain behind.

Chrome-steel is easily made by adding ferro-chrome to nearly finished steel in the furnace. Ferro-chrome with about 40 per cent. chromium is employed, and allowance is made for about 20 per cent. loss in the slag, which must be basic. For high-class tool steels it is preferable to use a refined ferro-chrome alloy containing from 60 to 75 per cent. chromium, made by reducing chrome iron ore in crucibles.

The effect of chromium in steel is, in general, to raise the tensile strength as the percentage of chromium increases without diminishing at the same time the ductility seriously. Up to 1 per cent. of chromium has little or no effect, either on the tensile strength or hardness of the steel even on quenching. In the absence of carbon, as much as 4 per cent. of chromium produces no greater hardening than the same quantity of aluminium, but with about 1 per cent. of carbon and from 2 to 3 per cent. of chromium, great stiffness with undiminished toughness is attained. Such a material is suitable for armor-piercing projectiles, if suitably

*Jahresberichte der chemischen Technologie. 1883, p. 220.

hardened and tempered to give the formation of the intensely hard carbides of iron and chromium, suitable for penetration of armor plates.

Low-carbon chrome-steels can be forged well with up to about 12 per cent. chromium present but, as the carbon increases, forging makes the steel hard and brittle. This brittleness can, however, be easily removed by annealing, and the steel is rendered excessively hard by quenching in water.

In addition to shells, chrome-steel with about 1.2 per cent. of chromium is very suitable for making files. Other uses of this alloy are the manufacture of locomotive springs, tires and axles; dies and shoes for stamp batteries, and any tools requiring great hardness. Armor plate is frequently now made with a combined chrome-nickel steel. For safes, alternate layers of chrome-steel and wrought iron are welded together and cooled suddenly. The hardness of the quenched chromium steel resists the burglar's drill, while the ductility of the wrought iron resists the blows of his sledge-hammer.

Under the microscope the effect of chromium on steel is seen to be an interference with the growth of the iron crystals, the granular structure being very minute, and this, no doubt, accounts for the modifications which the chromium effects on the mechanical properties of steels. The effect is not proportional to the chromium content, small percentages being more active than larger amounts. At first the chromium seems to dissolve in the steel, but as the amount increases, a double carbide of iron and chromium is formed, which possesses great hardness. This occurs in the steel either as isolated globules, or it may be dissolved in the metallic matrix (on annealing at 2192° F.), bestowing a very high degree of hardness on the alloy.

Tungsten steel.—Although tungsten by itself melts only with great difficulty, it readily unites with iron, forming an alloy known as *ferro-tungsten*. Such an alloy containing

about 80 per cent. of tungsten is, for the preparation of tungsten-steel, added to the steel whilst in the ladle. It is, however, preferable to use crucibles for melting in the alloy for special high-grade tool-steel. Tungsten-steel does not make sound castings except with the addition of a small quantity of aluminium and silicon; the fluidity of the alloy is slightly less than that of ordinary steel. The general effect of tungsten in steel is to make it intensely hard and brittle. It is very difficult to forge, and it cannot be welded when the content of tungsten exceeds 2 per cent. One peculiarity of tungsten-steel is that in the absence of carbon its strength or hardness is not increased by tempering. With a higher content of tungsten the steel can be worked only with the greatest difficulty. The higher grades cannot be worked with the file, and as none of them can be tempered, they must be shaped at one forging, and then ground to the form desired. Tungsten-steel may be cast in the form of tools which can be ground to a fine edge. Like chrome-steel, tungsten-steel can be readily worked at a red heat, but has to be handled with the greatest care to obtain the best results. An addition of tungsten gives to steel a very fine and uniformly crystalline structure, and such steel is less affected by the atmosphere than ordinary steel. Tungsten-steel may also be prepared by adding metallic tungsten to the melted steel in a crucible.

Bending tests conducted on bars of tungsten-steel show that, as cast, the increase of the percentage of tungsten gradually diminishes the toughness, especially after 3.5 per cent. of tungsten is reached, this point being comparable with 1½ per cent. of tungsten if the bars are annealed at about 1652° F., and then water-quenched, when a distinct hardening is noticeable. Unlike either the manganese or nickel steels, which, although brittle during the range from 3 to 7 per cent. for manganese and from 10 to 15 per cent. for nickel, become tough with higher percentages, tung-

sten-steel does not show this peculiar return to toughness, since the angle through which the bars bend decreases with the increase of tungsten.

On fracture the tungsten-steels show very marked peculiarity. First a very fine crystalline structure commences with 1.5 per cent. of tungsten, and up to 7 per cent., the grain is extremely close, but not silky. This characteristic appearance of silkiness only appears when the carbon content exceeds 1¼ per cent. and is apparently, therefore due to the presence of a carbide of tungsten in association with the carbide of iron.

Tungsten-steels with a high content of carbon are very retentive of magnetism, and an alloy with 5 per cent. tungsten, with 0.62 per cent. carbon and 0.55 per cent. manganese, is found very suitable for the manufacture of permanent magnets in electric meters. The highest magnetic power attainable with the greatest retentiveness is reached when the tungsten content is varied between 4 and 7 per cent. Low-carbon steels with tungsten do not show this magnetic retentiveness.

The special use of tungsten is for the production of self-hardening steels, that is, those which can be made hard enough to retain a cutting edge by heat treatment alone, without water-quenching. Such steels, if plunged when red hot into water, simply crack or split. They usually contain from 5 to 8 per cent. of tungsten, with 1.5 to 2.5 per cent. of carbon. The following are some typical analyses of special tungsten-steels. *

Analysis per cent.

	Carbon	Tungsten	Manganese	Silicon	Chromium
Mushet (Osborn)	1.65	5.8	2.12	1.36	0.45
Allevard	0.42	6.22	0.29	0.5	—
Mushet (ordinary)	2.0	7.81	0.19	0.9	—
Mushet (special)	2.3	8.22	1.72	1.60	—

* Greenwood. "Steel and Iron."

The first mentioned steel is peculiar in that it can be successfully softened for machining by heating to the temperature of incipient redness (about 932° F.) and quenching in water.

The second-named steel, of French manufacture, can, by quenching in water at 1112° F., be rendered (*a*) very hard; (*b*) of only medium hardness; or (*c*) quite soft, according as the temperature of the preliminary heating is raised to (*a*) 2372° F.; (*b*) 1832° F.; or (*c*) 1562° F.

The Taylor and White special "quick speed" cutting steels with 5 per cent. of tungsten, 4 per cent. of molybdenum and 4 per cent. of chromium can be worked at a red heat without losing their cutting edge. The temper of tools made from this alloy cannot readily be destroyed even when the rate of cutting makes the working face of the tool approach a low red heat.

Vanadium-steel.—The element vanadium was discovered about a century ago in a lead ore from Zimapan, Mexico, by the Mexican mineralogist Del Rio who, by reason of its forming red salts, christened it *erythronium*. This discovery, however, was later on discredited, Collet-Descotils declaring erythronium to be impure chromium and the mineral from which it was obtained, a lead chromate. Wöhler, however, later on proved the mineral to be lead vanadate. In 1830 the element was re-discovered by Sefström, in bar iron from Eckersholm, Sweden, and was called by him vanadium in deference to the Scandinavian deity Vanadis (a by-name of the goddess Freia). The element was isolated, about thirty years later, by Sir Henry Roscoe.

While vanadium was formerly considered only of scientific interest, it has during the past few years sprung into the position of a metal which has practically marked an epoch in the history of the steel-trade, its alloy with iron, known as vanadium-steel forming a highly valuable material in the construction of automobiles, locomotives, etc.

It was already surmised by Dick that a small content of vanadium would increase the ductility of iron, and Hélouise* also concluded that by an addition of vanadium, steel would be rendered especially tenacious. He arrived at this conclusion from the fact that Taberg wrought iron, which contains vanadium, is the softest of all Swedish brands of iron, and that many blast-furnace cinders in Staffordshire, England, where a very ductile iron is produced, show a considerable content of vanadic acid. To clear up the matter, he prepared aluminium-vanadium by reducing vanadium by means of aluminium powder, and from this made alloys of vanadium with ferro-aluminium, ferro-nickel and ferro-cyanide, and added them to liquid steel in a crucible. The steel, produced by the basic process, showed a compressive strength of 48 kilogrammes and an elongation of 16.9 per cent. By being previously melted, without an addition, in a graphite crucible, it absorbed much carbon, and then showed a compressive strength of 96 kilogrammes and an elongation of only 2.3 per cent. The basic steel was then treated three different ways:

a. The raw material together with 1 per cent. vanadium was remelted in a graphite crucible. The sample when forged, but without being annealed, showed a compressive strength of 109 kilogrammes and an elongation of 7.53 per cent.

b. Steel with 0.5 per cent. vanadium in a crucible brasqued with magnesia had a compressive strength of 66 kilogrammes, and an elongation of 16 per cent.

c. With 1 per cent. vanadium, a compressive strength of 97 kilogrammes and an elongation of 14 per cent., and when annealed a compressive strength of 71 kilogrammes and an elongation of 20 per cent.

The latter material which is very soft by itself acquires, on hardening, an extraordinary degree of hardness. White

* Stahl and Eisen, 1896, No. 16.

iron with a compressive strength of 38 to 39 kilogrammes and an elongation of 19 per cent. showed, with an addition of 0.5 per cent. vanadium, a compressive strength of 61.25 kilogrammes and an elongation of 12 per cent. in an unannealed state, and after annealing a compressive strength of 53 kilogrammes and an elongation of 32 per cent.

According to J. Kent Smith,* two varieties of steel, otherwise equal, but one of which contains 0.53 per cent. vanadium, show the following properties.

	With vanadium.	Without vanadium.
Tensile strength	72.42	62.50
Limit of elasticity	50.75	35.70
Ductility	6.25	8.00
Reduction of cross-section	5.90	7.80

After annealing,	Tensile strength in tons.	Ductility in per cent.
Soft steel	30	17
Same with 1 per cent. vanadium	61	14
The latter annealed	45	20

Effect in wrought iron.	Tensile strength in tons.	Ductility in per cent.
Wrought iron	24.5	19
Same with 0.5 per cent. vanadium, hardened	39	12
The latter annealed	33	32

Bending tests by Professor Arnold have shown that vanadium-steel will stand a much higher alternating stress than steels containing any of the other alloys. A high

*Jour. Soc. Chem. Ind., 20, 1183.

carbon may break at 100 alternations. Steels of the best acid or open-hearth casting will run as high as 290. An excellent quality of nickel-steel ran to 270, while vanadium-steel has attained as high as 570, or nearly 100 per cent. better than a good nickel compound.

To get the best results vanadium must be used in extremely small quantities. A little goes a great way, too much being as useless as not enough.

In speaking of vanadium in an address before the Central Railway Club at Buffalo, N. Y., March 8, 1907, Mr. J. Kent Smith says: "Its action is very powerful; it may be said that vanadium is to metallurgy what strychnine is to medicine, and therefore it is only used in small quantities."

"Vanadium increases the strength of steel 'per se,' but to the greatest extent by acting through another constituent (present in such quantities as not to dynamically 'poison' the steel in question), while it confers in itself to steel properties of great dynamic value. This first is exemplified by the following table."

Comparative effects of chromium and vanadium on static tests.

Rolled Bars Untreated.	Lbs. per sq. in. elastic limit.	Ultimate tensile stress.	Elongation on 2 in.	Reduction of area.
	Lbs. per sq. in.	Lbs. per sq. in.	Per cent.	Per cent.
Crucible Steels				
Plain carbon-manganese	35,840	60,480	35	60.0
" + 0.5 per cent. chromium	51,296	76,160	33	60.6
" + 1.0 " "	56,000	85,568	30	57.3
" + 0.1 " vanadium	63,840	77,052	31	60.0
" + 0.15 " "	68,096	81,750	26	59.0
" + 0.25 " "	76,384	88, 32	24	59.0
" + 1 per cent. chromium + .15 " vanadium	81,088	108,864	24	56.6
" + 1 " chromium + 0.25 " vanadium	90,496	135,296	18.5	46.3
Open-hearth Steels				
Plain carbon-manganese	39,648	72,128	34	52.6
" " + 1 0 per cent. Chromium + 0-15 " Vanadium	77,056	116,480	25	55 5

"Vanadium, however, can be regarded as a 'master' alloy, in that it can act in totally different ways, and by judiciously using it in the line one wishes to follow, steels

of great dynamic super-excellence, great static super-excellence, or with combinations of both, are attainable, such as can be obtained by *no other known means.*"

"The following table illustrates type of this:"

Automobile purposes are taken owing to requirements of same being of the most exigent nature.

Nature.	Tests.	1 Carbon "Axle" Stock.	2 Nickel "Axle" Stock.	3 Vanadium Axle Steel.	4 Vanadium Crank-Shaft Steel.	5 Vanadium "Continual Mesh" Gear Steel.
Static	Yield Point (lbs. sq. in.)	41,330	49,270	63,570	110,100	224,000
	Ultimate Stress	65,840	87,360	94,080	127,800	232,750
	Ratio	.62	.56	.66	.87	.96
	Elongation p. c. on 2 in.	42	33	33	20	.11
	Reduction of Area	61%	58%	61%	58%	39%
	Torsional Twists	2.6	3.2	4.2	2.5	1.8
Intermediate	Alternating Bends	10	12	18	10	6
Dynamic	Resistance to Pendulum Impact (ft. lbs.)	12.3	14	16.5	12	6
	Alternating Impact Number of Stresses	960	800	2,700	1,800	800
	Falling Weight on Notched Bar, Number of Blows	25	35	69	76	.....
	Rotary Vibrations, Number of Revolutions	6,200	10,000	67,500	.....	.....

N. B.—All figures obtained under comparative conditions.

The initial material for the preparation of vanadium-steel is vanadate (lead vanadate), which in a comminuted state is brought into double its weight of saltpeter-cake. After the, at first, violent effervescence, the mass which becomes gradually thicker is moderately heated for 20 to 30 minutes, and then drawn off. The solidified melt is pulverized, washed with water and for several hours thoroughly stirred, steam being at the same time introduced. Iron plates are then for four to six hours suspended in the vessel, whereby the contents of the latter separate into a white precipitate containing lead sulphate, silicic acid and unchanged ore, and into a dark green to blue fluid which contains the vanadium as sulphate or double sulphate. The fluid is siphoned off and compounded with 25 per cent. soda-lye so

long as a precipitate is formed. This precipitate is filtered in a filtering press, washed and dried; it forms a black mass which contains 18 per cent. vanadic anhydride V_2O_5.

The oxide mixture thus obtained may be reduced according to Goldschmidt's process by igniting, by means of a fulminating pellet, 15 parts of the oxide mixture with 4.5 parts of aluminium whereby a regulus is obtained which contains 14.9 per cent. vanadium, 58.1 per cent. iron, 26 per cent. aluminium; and 1.5 per cent. silicon. Or the oxide mixture is reduced in an electric furnace by heating 8 parts of it with 2 parts charcoal to the melting point, and introducing into the melt, in small portions at a time, 1 part of aluminium. The regulus obtained according to this method contains 16 per cent. vanadium, 70 per cent. iron, 2 per cent. silicon and 12 per cent. aluminium carbide.

According to an article in "The Mining Journal," vanadium steels may be grouped in three classes: (1) Those containing vanadium alone; (2) Those with vanadium and nickel; and (3) vanadium and chromium. The following are some interesting results obtained by addition of vanadium:

	Tensile Strength in lbs. per sq. in.	Limit of Elasticity in lbs. per sq. in.
Mild steel, low percentage of phosphorus	60,000	35,000
Mild steel, carbonized with cast iron in graphite crucible	62,000	47,000
Mild steel, with 0.5 per cent. of vanadium	94,000	74,000
Mild steel, with 1 percent. of vanadium, not annealed	138,000	112,000
Mild steel, with 1 per cent. of vanadium, not annealed	102,000	82,000

This 1 per cent. vanadium steel is usually employed for objects subjected to vibrations, as it resists the effects of traction admirably.

The second class of vanadium steels is that containing vanadium and nickel. The proportion is usually 0.2 and

0.4 per cent. vanadium and 2 to 6 per cent. nickel. With these steels a tensile strength of 78,000 to 87,000 lbs. per sq. in. is obtained; elasticity of 55,000 to 70,000 lbs. per sq. in., and elongation varying from 30 to 35 per cent. After tempering, the resistance to tension and limit of elasticity attain 220,000 and 195,000 lbs., and elongation falls from 10 to 8 per cent. Nickel has a peculiar action, as it makes steel hard until 8 per cent., and from 8 per cent. to 15 per cent. so brittle that one can break it with a hammer; from 15 to 25 per cent. extensibility rapidly augments to become almost stationary. Vanadium makes nickel steel more homogeneous, decreases fragility which nickel tends to give steel, though we must add that it is rarely employed with more than 8 per cent. of nickel. Such steel, from the fact that nickel gives a very great resistance to impact, is specially suited for piston rods, connecting rods, small shafts, etc.

In the third class of vanadium steels we have vanadium chrome-steels, the two best proportions for which are as follows :

Carbon	0.20	0.40 per cent.
Chromium	1	1
Vanadium	0.20	0.20

Chromium augments the resistance to impact and tension, but has a tendency to produce a very hard metal, difficult to work hot, and welding can only be operated successfully by electricity, owing to the tendency of chromium to oxidize and form slag. Chromium gives a steel difficult to cut and work cold, and the Carnegie Steel Company could find nothing better to cut this steel plate than a disk revolving at a very great rate of speed. This disk, 6 ft. in diameter, mounted like a circular saw, cuts plates 6 ins. thick; a jet of steam plays continually on the part being cut. Vanadium in the proportion of 0.15 to 0.25 per cent. counterbalances the tendency of chromium and facilitates cutting.

The steel is particularly suitable for crank-shafts, cranks, propeller shafts, locomotive and wagon axles, journals, etc. The following are results of experiments which clearly show the influence of vanadium on chrome:

	Tensile strength, in lbs. per sq. in.	Elastic limit, in lbs. per sq. in.	Reduction of area, per cent.	Elongation, per cent.
Manganese carbon steel.....	56,000	33,000	60	35
The same plus 0.5 per cent. chromium	71,000	46,000	61	33
" " 1 " "	80,000	51,000	57	30
" " 0.10 " vanadium	71,000	60,000	60	31
" " 0.15 " "	75,000	64,000	59	26
" " 0.25 " "	81,000	71,000	59	24
" " 1 per cent. chromium and 0.15 per cent. vanadium..	101,000	75,000	57	24
" " 1 per cent. chromium and 0.25 per cent. vanadium..	128,000	104,000	46	19
" " 1 per cent. chromium and 0.25 per cent. vanadium tempered.....	178,000	148,000	48	16
" " 1 per cent. chromium and 0.25 per cent. vanadium tempered.....	203.000	188,000	45	12

Nickel-steel.—This alloy of iron with nickel has been referred to under nickel alloys.

Alloys of iron with other metals will be found under the respective headings.

CHAPTER XVI.

SILVER ALLOYS.

PURE silver possesses but little hardness, and articles manufactured from it would be subject to considerable wear. For this reason silver-ware is never made of the pure metal, but always of alloys with other metals, excepting certain chemical utensils which must be of pure silver, as alloys would be attacked by the substances to be manipulated in them.

The alloys of silver are of real interest only when they are made with gold, copper, or aluminium. With the other metals, with very few exceptions, they are of no use in the arts. The alloys of silver and gold, and silver and copper are those employed for articles of luxury and for coinage. The alloys of silver, gold and copper are used for the same purpose. An alloy of silver, copper and tin is made into a solder for plated-ware and false jewelry. In modern times alloys containing silver and nickel, or silver, nickel, and zinc, are much used for table utensils; they having a beautiful white appearance and being much cheaper than alloys of copper and silver, which were formerly exclusively used for the purpose.

Alloys of silver and aluminium.—These alloys have previously been briefly referred to. Aluminium and silver form beautiful white alloys, considerably harder than pure aluminium, and take a very high polish. They have the advantage over copper alloys of being unchangeable on exposure to the air and retaining their white color. It has, therefore, been proposed to alloy coins with aluminium instead of with copper, which would render them much

more durable, but the results of experiments made on a large scale were not satisfactory.

The alloys of aluminium and silver show very varying physical properties according to the content of aluminium. An alloy consisting of 100 parts of aluminium and 5 of silver differs but little from pure aluminium, but is considerably harder and takes a beautiful polish. An alloy of aluminium 169 parts and silver 5 possesses considerable elasticity, and is recommended for fine watch-springs and dessert knives. An alloy of equal parts of aluminium and silver shows a hardness equal to that of bronze.

Tiers-argent (*one-third silver*).—This alloy is chiefly prepared in Paris factories for the manufacture of various utensils, and as indicated by its name consists of silver 33.33 parts and aluminium 66.66. The advantages of this alloy over silver consist in the lower price and greater hardness; it is also stamped and engraved with greater ease than the alloys of copper and silver.

Alloys of silver and zinc.—Silver and zinc have great affinity for each other, and consequently are readily alloyed. The alloys are prepared by throwing the required quantity of zinc previously wrapped in paper into the melted and strongly-heated silver, stirring thoroughly with an iron rod, and pouring the fused mass at once into moulds. Alloys of silver and zinc can be obtained both ductile and flexible. An alloy consisting of zinc 2 parts and silver 1 has nearly the color of pure silver and is quite ductile. With a larger proportion of zinc it becomes, however, brittle. In preparing the alloy a small quantity of zinc volatilizes, and hence somewhat more has to be taken than the finished product is to contain.

By pouring melted zinc into melted silver, G. H. Godfrey* prepared the following alloys:

	I.	II.	III.	IV.
Silver	8.16	22.47	49.72	67.58
Zinc	91.84	77.53	50.28	32.42

*Percy. Gold and Silver. Vol. I, p. 169.

The surface of I. was bluish-gray. The alloy was hard, easily frangible, and readily scratched with a knife. Its fracture was bluish-gray, finely granular and feebly lustrous.

The surface of II. was bluish-gray, The alloy was harder than I., readily frangible, but less easily scratched. Its fracture was bluish-gray, bright and fibro-columnar.

The surface of III. was copper-red after solidification. The alloy was hard, brittle and easily pulverized. The broken surface, when fractured cold, was white and very bright and somewhat columnar.

The surface of IV. had a faint reddish-yellow tint. The alloy was hard and easily frangible; its fracture white and very bright, but it soon tarnished ; its fracture was columnar.

Alloys of silver and zinc possess valuable properties, especially that of retaining their white color and being more fusible than silver-copper alloys. It has, therefore, been proposed to use them for coinage, and especially for small coins. Alloys with 5, 10, and 20 per cent. of zinc prepared with this object in view were white, with a tinge of yellow and the coins made of them more elastic and sonorous, and not as easily blackened by sulphuretted hydrogen as silver-copper alloys. Comparative experiments have, however, shown that for coins it would be preferable to use alloys, which, in addition to silver and zinc, contain copper, the following composition having been especially recommended for the purpose : Silver 835 parts, copper 93, zinc 72.

The alloy can be readily rolled into a sheet of suitable thickness, and should it become brittle its ductility may be restored by annealing.

Alloys of silver, copper, and nickel.—Nickel by itself makes silver very hard and brittle, such alloys being difficult to work into utensils. But by adding some copper the alloys can be cast, rolled, and fused, and the articles manufactured from them are harder than those from silver and copper alloys. Alloys of silver, nickel, and copper are much used by French manufacturers for articles formerly

prepared from standard silver. These compositions may be considered as an argentan whose properties have been improved by a content of silver.

Argent-Ruolz.—The articles manufactured by Ruolz, of Paris, from the so-called Ruolz silver, or *argent français*, have the appearance of pure silver, but are much cheaper and harder. According to the quality of the articles, different alloys are used, a few such compositions being given as follows:

	Parts.		
	I.	II.	III.
Silver	33	40	20
Copper	37 to 42	30 to 40	45 to 55
Nickel	25 to 30	20 to 30	25 to 35

C. D. Abel, of London, has patented in England several alloys containing silver and nickel. They are divided into two classes, the first consisting of alloys of silver, copper, and nickel, with or without an addition of manganese. The alloys of this class may be composed according to the following proportions:—

	Per cent.		
	A.	B.	C.
Silver	33	40	20
Nickel	25 to 30	20 to 30	25 to 35
Copper	37 to 42	30 to 40	45 to 55

The second group of these alloys consists of silver, copper, nickel and zinc, with or without manganese, and is composed of the following proportions:—

	Parts.		
	D.	E.	F.
Silver	333	340	400
Copper	418	420	446
Zinc	163	161	108
Nickel	86	80	46

Of the above-mentioned alloys A, D, and E are especially intended for rolled, pressed, or drawn silver articles, C for casting, and F for jewelry. The content of silver in these alloys varies from 20 to 40 per cent., according to the purposes for which they are to be used—the proportion of nickel being the less, the greater that of silver.

For the alloys of the first group the patentee uses the purest copper found in commerce and purified nickel, the purification of the latter being effected in the following manner: The ordinary impure nickel of commerce is dissolved in nitric acid or in dilute sulphuric acid, the solution in the latter case being promoted by connecting the nickel with the positive pole of a galvanic battery. The solution is treated with chlorine, and the ferric oxide precipitated by boiling with calcium carbonate. The solution is subsequently precipitated with soda, the precipitate re-dissolved in hydrochloric acid, the solution diluted with a large quantity of water, saturated with chlorine, and then treated with barium carbonate, and allowed to cool. From the fluid separated from the precipitate the nickel is subsequently precipitated by the galvanic method and then reduced.

Nickel-speiss can be treated by the dry method by melting 100 parts of it with 20 of saltpeter and 100 of feldspar, whereby the cobalt forms a blue glass. The residue is roasted, washed, and dissolved in sulphuric acid, the resulting fluid being treated in the same manner as above. But

no matter how the nickel may have been purified, it is of advantage before preparing the alloys to remelt it in a crucible together with yellow or red prussiate of potash, 50 parts of yellow or 25 to 30 of red prussiate of potash being used for the purification of the commercial nickel. Frequently this method alone suffices for the purification of the commercial nickel, which by these means is obtained in well-fluxed, homogeneous pieces of any desired size.

The nickel purified in the above or any other manner is melted with the copper and an addition of charcoal and yellow, or better, red prussiate of potash, which when used as flux, is claimed to impart special properties to the alloys. In preparing an alloy which is to contain the highest content of silver and the smallest of copper, it is of advantage to add some manganese to prevent oxidation as much as possible, since the addition of nickel, if exceeded above a certain proportion, would impair the quality of the alloy. For this purpose sufficient oxide of manganese previously glowed with charcoal in a closed crucible is added to the mixture of copper and nickel before melting so that a preliminary alloy, consisting of 80 to 90 parts of copper and nickel and 10 to 20 parts of manganese, is obtained—borax, red or yellow prussiate of potash, and charcoal being used as flux. The manganese readily combines with the copper, and the nickel and silver form with them a ductile alloy readily worked.

For the preparation of the alloys D, E, and F, the patentee employs the purest commercial copper and zinc and nickel purified by one of the methods above described. He first melts the copper and zinc together in the right proportions, and adds to the alloy thus obtained, the nickel by remelting, using the above-mentioned fluxing agents. For an alloy with a large percentage of silver, manganese is added in the same manner as above described.

The preliminary alloys thus obtained are subsequently melted together with the necessary quantity of silver, either

yellow or red prussiate of potash, charcoal or borax, together with phosphorus being added. For the production of an alloy of phosphorus and copper the use of phosphor-copper deserves the preference. Its content of phosphorus having been previously determined by an analysis, it is added to the argentiferous alloy in such a quantity that the content of phosphorus of the latter amounts to ½ to 2 per cent. The phosphor-copper is best prepared by heating 8 parts of comminuted copper with 1 part of a mixture of 40 parts of charcoal and 27 of superphosphate of lime. The final silver alloys can also be at once fused with this mixture of charcoal and superphosphate of lime previously heated to a slight red heat, using 1000 parts of the alloy to 100 of the mixture. By this process the content of phosphorus in the alloys will be the greater the longer the heating has been continued. The introduction of phosphorus makes the alloys more fusible and more homogeneous, and at the same time imparts to them a white color. To retain these advantages and to restore to the alloy its ductility lost by the addition of phosphorus, the latter is almost entirely removed, after homogeneous ingots have been obtained, by heating the alloy with charcoal powder in a closed crucible for several hours.

Alloys of silver, copper, nickel, and zinc.—These alloys have been used for the preparation of small coins, especially in Switzerland. The coins while wearing well, however, soon lose their original beautiful white color and acquire a disagreeable yellowish shade resembling the color of poor brass. For coinage these alloys have the further disadvantage of the silver contained in them being only regained by a very tedious process.

Alloys for Swiss fractional coins.

	20 centimes.	10 centimes.	5 centimes.
	Parts.	Parts.	Parts.
Silver	15	10	5
Copper	50	55	60
Nickel	25	25	25
Zinc	10	10	10

Mousset's silver alloy.—Copper 59.06 parts, silver 27.56, zinc 9.57, nickel 3.42. Color, yellowish with a reddish tinge, but white upon the fractured surface.

The argent-Ruolz sometimes contains also certain quantities of zinc. The following alloys can be rolled into sheet or drawn out into wire:—

	Parts.		
	I.	II.	III.
Silver	33.3	34	40
Copper	41.8	42	44.6
Nickel	8.6	8	4.6
Zinc	16.3	18	10.8

Alloys of silver and arsenic.—These alloys may be formed by direct fusion, and the silver will retain a certain proportion of arsenic even when the temperature is very high. The compound made of 86 parts of silver to 14 of arsenic is of a dead grayish-white color, brittle, and acquires a metallic luster by friction. It is very fusible. An alloy composed of silver 49 parts, copper 49 and arsenic 2, is very ductile and has a beautiful white color. It was formerly used for the manufacture of table-ware, for which it is, however, not suitable on account of the poisonous properties of the arsenic.

Alloys of silver, copper and cadmium.—Cadmium imparts to silver alloys great flexibility and ductility, without im-

pairing their white color. Some of the more important alloys of this group are composed of—

	Parts.						
	I.	II.	III.	IV.	V.	VI.	VII.
Silver	980	950	900	860	666	667	500
Copper	15	15	18	20	25	50	50
Cadmium	5	35	82	180	309	283	450

In preparing these alloys the great volatility of cadmium must be taken into consideration. The silver and copper are, as a rule, first alloyed; the cadmium wrapped in paper is then brought into the fused mass, the whole quickly stirred and at once poured into moulds. By this mode of procedure volatilization of cadmium is best prevented.

Silver is also used in the preparation of other alloys, particularly in connection with platinum, which will be referred to later on. No true alloys of silver and iron have been made, only more or less intimate mixtures, in which silver appears in the shape of drops or filaments. The alloys of silver with cobalt and chromium are generally very hard and brittle, and thus far have found no application in the industries.

Alloys of silver and copper.—These alloys are more used than any other compounds of silver, and in most countries form the legal composition of coins and silverware. Silver and copper are easily alloyed in all proportions, the combination taking place with expansion, and its specific gravity is less than that calculated from the proportions of the component metals. The copper imparts to silver greater hardness, strength, and toughness, the alloys acquiring the property of giving out a beautiful sound. The presence of copper does not modify the color of silver so long as the proportion of copper does not exceed 40 to 50 per cent.; a

greater proportion imparts to the alloy a yellowish tint similar to that of brass, and if the compound contains from 65 to 70 per cent. of copper the color is reddish, approaching that of pure copper.

The alloys of copper and silver, though easily prepared by the ordinary process of fusion, are, nevertheless, subject to the defect of separation, or "liquation," which necessitates certain precautions when running the metal into moulds. When such an alloy is run into a cold ingot mould, the center of the ingot shows a lower degree of fineness than the portion nearer the sides of the mould; and even in the monetary alloys all the portions are not of the same degree of fineness.

Formerly the silver used for coinage frequently contained small quantities of gold, and for this reason nearly all the older coins are treated in the mints by the wet method to regain the gold.

At the present time the fineness of all coins is determined by thousandths, the standard varying according to the size of the coins, and the laws of the different countries, from $\frac{900}{1000}$ to $\frac{750}{1000}$. In the following table the compositon of the silver coins of various countries is given:—

Country.	Coins.	Fineness.
Austria	Pieces of 3 and 2 guldens	900
Belgium	5-franc piece	897
"	2-franc piece	835
Brazil	Milreis, pieces of 500 and 200 reis	916
Denmark	Dobbelt rigsdaler, rigsdaler, halvdaler	875
"	Mark (1/6 rigsdaler)	500
East Indies	Pieces of 1, 1/2, 1/4, 1/8 rupee	916.66
Egypt	Pieces of 20, 10 and 5 piastres	833 1/3
"	Pieces of 1 piastre	755
"	Pieces of 1/2 and 1/4 piastre	750
France	Pieces of 5, 2 and 1 franc, and 50 and 20 centimes	835
Germany	Mark piece	900
Great Britain	Crown, half-crown and shilling	925
Greece	Pieces of 5, 1, 1/2 and 1/4 drachme	900
Holland	Pieces of 2 1/2, 1 and 1/2 gulden	945
Italy	Pieces of 5, 2, 1, 1/2 and 1/4 lira	835
Mexico	Peso (average by U. S. Mint assay)	901
"	Peso of Maximilian (average by U. S. Mint assay)	902 1/2
Norway	Pieces of 1, 1/2, 1/5, 1/10 specie daler	875
Portugal	Pieces of 500 reis (by U. S. Mint assay)	912
Prussia	Thaler pieces	900
"	Old Thalers before 1857	750
Russia	Pieces of 1, 1/2 and 1/4 ruble	768.5
"	Pieces of 1/5, 1/10, 1/20 ruble	750
Spain	Dollar of 5 pesetas	900
"	Peseta (present, by U. S. Mint assay)	835
Sweden	Riksdaler, crown and 1/2 riksdaler	750
Switzerland	Pieces of 2, 1 and 1/2 francs	800
Turkey	Pieces of 20, 10, 5 and 2 piastres	830
United States.	Dollar, half dollar, quarter dollar, dime, half dime and three-cent piece	900

The various silver-copper alloys employed in England for manufacturing purposes are given by Gee * as shown in the following tables :—

	I.			II.			III.			IV.		
	oz.	dwt.	gr.	oz.	dwt.	gr.	oz.	dwt.	gr.	oz.	dwt.	gr.
Silver	0	18	0	0	16	0	0	15	0	0	14	0
Copper	0	2	0	0	4	0	0	5	0	0	6	0

*Gee. Silversmith's Handbook.

	V.			VI.			VII.			VIII.		
	oz.	dwt.	gr.	oz.	dwt.	gr.	oz.	dwt.	gr.	oz.	dwt.	gr.
Silver.....	0	13	12	0	13	0	0	12	12	0	12	0
Copper.....	0	6	12	0	7	0	0	7	12	0	8	0

Alloy No. VIII. is about the commonest alloy possible to make without the color showing a perceptible yellow cast.

The fineness of silver used in the manufacture of silver-ware in different countries varies from $\frac{750}{1000}$ to $\frac{950}{1000}$, as shown by the following table:—

Countries.	Fineness.
Prussia, Saxony, Brunswick	780
Austria, Bavaria	812
England	925
France, Italy, Belgium	950 / 800

Silver alloyed with copper in the preceding proportions has, in form of wire or sheet, a hardness equal to that of cold-forged copper. By continued mechanical manipulation the hardness increases, however, and may be made equal to that of wrought-iron. Silver is also sometimes used for casting small articles of art, but it is difficult to obtain castings entirely free from blow-holes. This evil can, however, be readily prevented by adding to the alloy a small quantity of zinc, about 1 per cent. The resulting castings will be homogeneous, and free from blow-holes, while the ductility of the alloy is not in the least impaired by such a small percentage of zinc.

In consequence of the frequent annealing required in working articles of silver, they gradually acquire a steel-gray color, which is due to the oxidation of copper. Hence the finished articles must be subject to a special manipulation called "blanching." This is effected by boiling the articles in a fluid consisting of 40 parts of water and one

part of sulphuric acid. The oxide of copper readily dissolves in the mixture, leaving the surface of the article coated with a layer of chemically pure silver.

The Japanese have a remarkable series of alloys, in which the precious metals replace the tin and zinc of ordinary bronze, but really their main alloys with the exception of bronze are comprised in the following example given by Prof. W. C. Roberts-Austen in a paper read before the Society of Arts, June 13, 1890. The first is called

Shaku-do.—It contains:

	I.	II.
Copper	94.50	95 77
Silver	1.55	0.08
Gold	3.73	4.16
Lead	0.11	—
Iron and arsenic	traces	—
	99.89	100.01

As will be seen from the analyses, the alloy contains in addition to about 95 per cent. of copper as much as 4 per cent. of gold. It has been used for very large works. Colossal statues are made of it, one cast at Nara in the seventh century being especially remarkable. The quantity of gold is, however, very variable, and certain specimens contain only 1.5 per cent. of the precious metal.

The next important alloy used by the Japanese is called *Shibu-ichi*, the following being typical analyses of it:

Copper	67.31	51.10
Silver	32.07	48.93
Gold	traces	0.12
Iron	0.52	—
	99.90	100.15

There are many varieties of it, but in both these alloys—skaku-do and shibu-ichi—the point of interest is, that the precious metals are, as it were, sacrificed in order to produce definite results, gold and silver, when used pure, be-

ing employed very sparingly to heighten the general effect. In the case of shaku-do, it will be seen presently that the gold appears to enable the metal to receive a beautiful rich purple coat or patina when treated with certain pickling solutions, while shibu-ichi possesses a peculiar silver-gray tint of its own, which, under ordinary atmospheric influences, becomes very beautiful, and to which the Japanese artists are very partial. These are the principal alloys, but there are several varieties of them as well as combinations of shaku-do and shibu-ichi in various proportions, as, for instance, in the case of kin-shibu-ichi, the composition of which would correspond to one part of skaku-do rich in gold, and two parts of shibu-ichi, rich in silver.

With regard to the use of pickling solution, they are made up respectively in the following proportions, and are used boiling:—

Verdigris	438 grains	87 grains	220 grains
Sulphate of copper	292 grains	427 grains	540 grains
Nitre	—	87 grains	—
Common salt	—	146 grains	—
Sulphur	—	233 grains	—
Water	1 gallon	—	1 gallon
Vinegar	—	1 gallon	5 fluid drachms

The most widely employed is No. I. When boiled in No. III. solution, pure copper will turn a brownish-red, and shaku-dō, which contains a little gold, becomes purple. The effect of small quantities of metallic impurity as affecting the color resulting from the action of the pickle will be appreciated from the following remarks: Copper containing a small quantity of antimony gives a shade very different from that resulting from the pickling of pure copper. But the copper produced in Japan is often the result of smelting complex ores, and the methods of purification are not so perfectly understood as in the West. The result is that the so-called "antimony" of the Japanese art metal-workers, which is present in the variety of copper called "kuromi," is really a

complex mixture containing tin, cobalt, and many other metals, so that a metal-worker has an infinite series of materials at command with which to secure any particular shade; and these are used with much judgment, although the scientific reason for the adoption of any particular sample may be hidden from him. It is strictly accurate to say that each particular shade of color is the result of minute quantities of metallic impurity.

The action of the above-mentioned solutions is remarkable. Take copper to which a small amount of silver and a small amount of gold are added. The amount of gold may be variable, and artificers often take credit for putting in much more than analysis proves to be present, but a small amount of gold, it may be only 1 per cent., is sufficient to entirely change the character of copper, and when it is treated by pickling solutions the result is entirely different from that if copper alone is employed. The Japanese also take copper and dilute it, sometimes half copper and half silver, sometimes only about one-third silver and all the rest copper, and that gives the lovely series of gray alloys, which, either by exposure to atmospheric influences, by handling or by treatment with suitable pickles, gives the beautiful series of light and dark grays of which the Japanese are so particularly fond, and to grays to which the name *shibu ichi* is given. Then again they have copper in which small amounts of impurities may be present, and the nature of such impurity and the amount, which seldom exceeds two-tenths per cent., is quite sufficient to change the character of the copper. The Japanese working in no small measure by rule of thumb, find that certain varieties of copper are best suited for definite processes, and store them up and use them in definite ways.

Other Japanese alloys of special interest are those to which the names *moku-me (wood-grain)* and *niyu-nagashi (marbled)* are given. The characteristic alloys which the Japanese employ are taken in thin sheets and soldered to-

Clark's patent alloy consists of shot-copper 1 ounce, nickel 3 dwts. 18 grains, spelter 1 dwt. 22 grains, tin 12 grains, cobalt 12 grains.

Pirsch-Baudoin's alloy.—This alloy, resembling silver, is composed of copper 71 parts, nickel 16.5, cobalt (in the form of oxide) 1.75, tin 2.5, and zinc 7. Some aluminium (about ½ per cent.) may also be added. Prepare first an alloy of all the nickel, an equal quantity of the copper and the zinc; then melt this alloy together with the iron, the remainder of the copper, the cobalt, and some charcoal powder under a surface covering of charcoal powder in a graphite crucible at a strong heat. Allow the melted mass to cool and then add the zinc, previously alloyed with copper, at a temperature just sufficient for its fusion. Now take the crucible from the fire, stir the contents with a wooden stick, add the tin previously wrapped in paper, stir the mass once more, and pour out into moulds. But a small quantity of zinc remains in the alloy, the greater portion of it volatilizing during fusion.

CHAPTER XVII.

GOLD ALLOYS.

Gold has been known and used by every nation, both uncivilized and civilized, from the earliest period down to our time. It is found among the old Egyptian monuments, and semi-barbarous nations have used it in the form of dust as the principal medium of exchange, the instrument of association. When America was discovered by Columbus gold was well known to its inhabitants; the Chinese have used it from time immemorial; the Medes and Persians were remarkable, even more than other Asiatics, for their love of gold; jewels of costly description were employed to indicate the rank of the wearer, and this custom is still continued in the East at the present time. To show the sacred value the Egyptians in ancient times placed on gold, it was represented by a circle with a dot in the middle, this circle amongst that nation being the symbol of divinity and perfection.

Gold is one of the metals which most readily enter into combination with other metals. But this property is without importance when we consider the inutility of the majority of the compounds, and the necessity of not debasing its value or impairing its properties. Moreover, it is certain that excepting its alloys with copper, silver, iron, and platinum, the latter two being without actual utility, gold loses part of its ductility, resistance, and cohesion, when it is combined with other metals such as zinc, tin, lead, etc. Therefore, it is entirely useless to experiment on those alloys where gold loses not only a part of its money value, but also those valuable properties which participated in making it a noble metal.

The principal alloys of gold used at the present time are those with copper or silver, or, in rare cases, with both these metals.

Gold and copper have great mutual affinity and may be alloyed in all proportions. The alloys are harder and more fusible than gold alone. Copper diminishes the ductility of gold when it enters into the combination in a proportion over 10 to 12 per cent. The specific gravity of an alloy of gold and copper is less than the average of the two metals. The color of the alloy varies between dark yellow and red, according to the quantity of copper. Pure copper must be used in the preparation of the alloys, as the impure metal alters the malleability of gold and may render it brittle.

Gold and silver may be easily mixed together, but do not appear to form true combinations. These compounds are more fusible than gold and are generally greenish-white, more ductile, harder, more sonorous and elastic than gold or silver considered singly. One-twentieth of silver is sufficient to modify the color of gold. Silver, like copper, increases the firmness of gold, and on that account it is employed at various degrees of fineness for jewelry work. These alloys are known by jewelers under the names of *yellow gold*, *green gold*, and *pale gold*, according to the proportion of silver.

As previously mentioned, the alloys of gold with other metals are of no practical utility and need only be briefly referred to. Gold alloyed with iron forms pale gray masses, brittle, and somewhat magnetic. An alloy holding $\frac{1}{6}$ of iron is employed in jewelry under the name of *gray gold*.

Lead shows a peculiar behavior towards gold. Both metals are very soft and ductile, but when alloyed they form an exceedingly brittle metal of a pale yellow color, strongly crystalline, and hard as glass. According to Berthier, one-half of one-thousandth of lead alloyed to gold is sufficient to render the latter metal entirely brittle and without ductility.

Arsenic or antimony alloyed with gold gives a brittle, very crystalline alloy of a white or gray color. Accidental admixtures of arsenic or antimony can, however, be removed in a simple manner, it being only necessary to keep the metal in a melted state for some time, whereby the arsenic and antimony volatilize, the pure gold remaining behind.

Alloys of gold and palladium.—By alloying palladium 1 part with gold 1 part a gray alloy is formed. It has the color of wrought-iron, is less ductile than either of the component metals, and of a coarse-grained fracture. A hard, ductile alloy is formed with 1 part palladium and 4 parts gold, and an almost white alloy with 1 part palladium and 6 parts gold. Alloys of gold, copper, silver and palladium have a brownish-red color and are as hard as iron. They are sometimes used for bearings of the arbors in fine watches as they cause the minimum of friction (less than the jewels used for the same purpose) and do not rust. A typical alloy for watches consists of gold 18 parts, copper 13, silver 11, palladium 6. For parts of watches which require to be very hard an alloy of 80 parts gold and 20 parts palladium is also used.

Alloy of aluminium and gold.—This alloy, also known as *Nuremberg gold*, is frequently used in the manufacture of cheap gold ware, it being well adapted for the purpose as its color exactly resembles that of pure gold and remains unchanged in the air. The composition of most articles of Nuremberg gold is according to the following proportions: Copper 90 parts, gold 2.5, aluminium 7.5.

An addition of cadmium to an alloy of gold and silver imparts to it a beautiful green color. These alloys will be referred to in speaking of colored gold.

Preparation of Gold Alloys.

The preparation of the alloys varies according to the purpose for which they are to be used, this difference being es-

pecially apparent in the moulds employed for casting. The manufacturers of gold articles rarely use moulds for shaping the articles, excepting such as have considerable thickness, as seal-rings, medals with especially high relief, etc. The casting of such articles is generally effected in moulds of very fine sand, or finely pulverized and elutriated cuttle-fish.

For coinage the gold is always cast into ingots or bars, iron moulds being generally used for the purpose. The bars are either rolled out to sheet or drawn into wire, the larger part of jewelry being also manufactured from such sheet or wire. The shape of the moulds used for casting varies according to the shape the ingot is to have; for ingots to be drawn out into wire it is best to use cylindrical tubes open on top and closed on the lower end by an iron plug. The gold contracting strongly in solidifying can be removed from the tubes without difficulty.

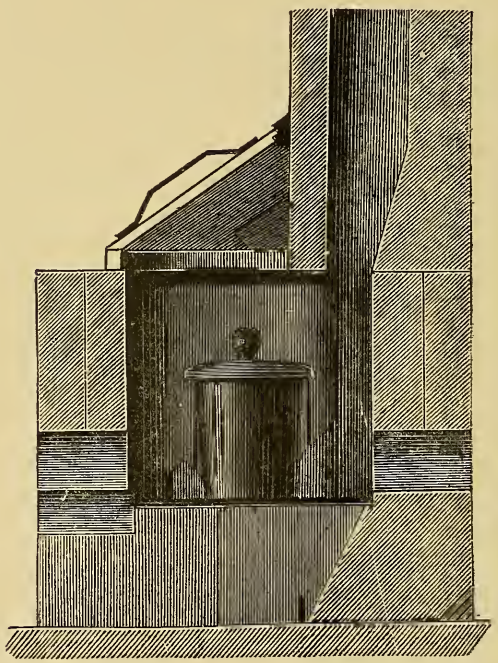
Ingots to be used for the preparation of gold plates are best cast in the form of four-sided prisms, casting ladles with a corresponding bowl being used for the purpose. For casting very thin plates upright ladles covered with a level plate are also used.

The melting of the metals constituting the alloys is always effected in graphite crucibles, the gold being in all cases first melted, and as it does not oxidize even at a red heat a protecting cover is not required. The gold being entirely melted, it is heated as strongly as the furnace will permit, and the other metals previously converted into small pieces are then introduced. On account of the great density of gold as compared with that of the other metals, the mixture of the metals is promoted by stirring with an iron rod sharpened on the point and made previously red hot. The crucible is then quickly withdrawn and its contents poured into a suitable ingot mould, previously warmed and greased to prevent adhesion. The warming of the mould is quite indispensable, but if made too hot the metal on

being turned into it will spit and fly about, and besides incurring great loss of gold, dangerous results might thereby happen to the person in charge. The same remark applies when the ingot mould is cold. It is hot enough when the hand will just stand touching it for a second or so.

The melting point of gold being very high, the furnace used should have a good draught. In some mints which

Fig 40.



alloy daily large quantities of gold and silver, furnaces heated by gas are used.

The furnace used by most manufacturers of gold-ware is, however, the wind-furnace, one admirably suited for the purpose being shown in Fig. 40. The crucible and fuel are introduced through an oblique iron door lined inside with fire-clay. These furnaces can also be used for the prepara-

tion of granulated gold, frequently used by gold-workers in the manufacture of jewelry. For this purpose thin sheet-gold or wire is cut with scissors into small pieces, which are enveloped in charcoal dust in a graphite crucible, and heated in the furnace. The pieces of gold melt to small balls of corresponding dimensions, which, after being freed from adhering foreign bodies by washing, are separated into sizes by passing through a sieve.

When it is desired to produce very tough gold, use as flux a tablespoonful of charcoal and one of sal ammoniac, adding it to the gold just before melting; the sal ammoniac burns away while toughening the gold. The employment of this mixture of sal ammoniac will bring the ingots of gold up bright and clear; it will also prevent them from splitting or cracking when rolled and in subsequent working.

In remelting scrap-gold from the work-shop and old gold, care should be taken that they are not too much contaminated by solder and are free from organic matter, wax, etc. The solder used in soldering gold-ware contains tin, lead, bismuth, and sometimes zinc, and the presence of these metals has an injurious effect upon the ductility of the gold. It is recommended to separate much-contaminated gold from the foreign metals by the wet process, and alloy the resulting chemically pure gold.

In most countries there are legally fixed standards for gold alloys. Generally such alloys are considered as consisting of so many carats to the unit, the pound, or half pound being divided into 24 carats, each of which contains 12 grains. What is termed 18 carat gold is a unit of 24 carats of alloy containing 18 carats gold and 6 of copper. Since the introduction of the decimal system in many countries the fineness of gold alloys has been determined by thousandths, the fineness of the alloys being officially expressed in this manner. Notwithstanding the simplicity of the system, many manufacturers still hold to the old method and calculate according to carats and grains. To save

calculation the conversion of carats and grains into thousandths is given in the following table:

1 grain=	3.47	7 carats=	291.666
2 "	6.95	8 "	333.333
3 "	10.42	9 "	374.999
4 "	13.89	10 "	416.667
5 "	17.36	11 "	458.630
6 "	20.84	12 "	500.000
7 "	24.31	13 "	541.667
8 "	27.78	14 "	583.333
9 "	31.25	15 "	624.555
10 "	34.73	16 "	666.667
11 "	38.19	17 "	707.333
12 "	41.67	18 "	750.000
1 carat=	41.667	19 "	791.666
2 "	83.334	20 "	833.333
3 "	125.001	21 "	874.999
4 "	166.667	22 "	916.666
5 "	208.333	23 "	958.333
6 "	250.000	24 "	1000.000

Use of Gold Alloys.

Gold alloys are principally used for coinage and ornamental articles. They are further employed in the manufacture of genuine gold-leaf, in the preparation of genuine *Leonis* wires (which consist of silver coated with gold), and in filling teeth.

Standard gold.—The alloy used at present in all countries for gold coins consists of gold and copper. Many coins contain a small quantity of silver, but this is due to a contamination of the copper with this metal, many copper ores containing silver, but in such small quantities that the separation of the two metals would not pay. As coins are subjected to considerable wear through frequently passing from hand to hand, the amount of loss occasioned thereby is worthy of some little consideration. Of course, this amount will be in proportion to the length of time the coins have been in circulation. To provide against this the English government allows a sovereign to be a legal tender

till it is reduced not below 122.5 grains, the difference between this and the full standard weight of 123.147 grains being the remedy allowed by English law for abrasion or loss by wear. The depreciation of a coin depends upon its hardness, wearing much more when soft, and also upon the rapidity of circulation. In most countries the fineness of gold coins is fixed by law, and though, as will be seen from the following table, the differences are slight, commerce would be greatly facilitated if all countries would adopt a universal standard of fineness:

Ducats, Hungarian	989 thousandths.
" Austrian	986 "
" Dutch	982 "
English sovereigns	916 "
Prussian Friedrichsd'or	902 "
German gold coins, Austrian crowns, French gold coins, Belgian, Italian, Swiss, Spanish, Greek, United States, Chinese	900 thousandths.
Older German gold coins (pistoles)	895 "

In the manufacture of jewelry alloys of gold with copper, or with silver, or with both metals are used. The alloy with copper alone is termed *red*, while if silver is used it is termed *white*, and if both metals are alloyed with gold the caratation is termed *mixed*. In most countries there are legally fixed standards for gold jewelry. In England 16, 18, and 22 carat gold is stamped, or, as it is termed *Hall marked*, in France 18, 20, and 22 carat, in Germany 8, 14, and 18 carat, and, also, under the term *joujou* gold, a 6 carat gold used for jewelry to be electro-gilt. Though this is intended as a protection to the buyer, the price of the articles does not depend alone on the quantity of gold used,

but to a great extent on the labor expended on its production, and, therefore, these legal regulations are, in many cases, illusive.

In the following table the gold alloys legally fixed by the various governments are given, but it may be remarked that for certain ornamental articles distinguished by their color some deviation, though within certain limits, is permitted:

Fineness.	Parts.			Color.
	Gold.	Silver.	Copper.	
583	14	6	4	yellow.
583	14	3	7	dark yellow.
583	14	1	9	very red.
666	16	4.66	3.33	yellow.
666	16	1.60	6.40	red.
750	18	3.50	2.50	yellow.
750	18	2.50	3.50	red.

Gold alloys which can be legally used in various countries.

		Fineness.
England		750
France, Belgium, Italy	highest standard	920
France, Belgium, Italy	second "	840
France, Belgium, Italy	third "	750
Austria,	No. I.	326
"	No. II.	545
"	No. III.	767

Pforzheim gold-ware.

	Fineness.
Ordinary ware (joujou)	130 to 250
Finer quality	563
Finest quality	583 to 750

	Gold. Parts.	Silver. Parts.	Copper. Parts.
Elastic gold alloy (spring gold)	2.66	2.66	5.33

The following table shows the proportions of various metals incorporated in the gold alloys used by jewelers;

Carats.	Parts.		
	Copper.	Silver.	Gold.
23	½	½	23
22	1	1	22
20	2	2	20
18	3	3	18
15	6	3	15
13	8	3	13
12	8½	3½	12
10	10	4	10
9	10½	4½	9
8	10½	5½	8
7	9	8	7

Colored gold.—As previously remarked, the color of gold alloys varies according to the proportions of copper or silver used. Manufacturers of jewelry and other gold-ware make extensive use of the various colors of alloys, one article being frequently composed of several pieces of different colors. The appended table gives the composition of the alloys most frequently used, with their specific colors :—

Parts.					Color.
Gold.	Silver.	Copper.	Steel.	Cadmium.	
2 to 6	1.0	—	—	—	green.
75.0	16.6	—	—	8.4	"
74.6	11.4	9.7	—	4.3	"
75.0	12.5	—	—	12.5	"
1.0	2.0	—	—	—	pale yellow.
4.0	3.0	1.0	—	—	dark yellow.
14.7	7.0	6.0	—	—	"
14.7	9.0	4.0	—	—	"
3.0	1.0	1.0	—	—	pale red.
10.0	1.0	4.0	—	—	"
1.0	—	1.0	—	—	dark red.
1.0	—	2.0	—	—	"
30.0	3.0	—	2.0	—	gray.
4.0	—	—	1.0	—	"
29.0	11.0	—	—	—	"
1 to 3	—	—	1	—	blue.

The alloys containing cadmium, given in the above table, are malleable and ductile, and can be used for plating. To prepare them the constituent parts must be carefully melted together in a covered crucible lined with coal dust. The resulting alloy is then remelted with charcoal, or powdered rosin and borax in a graphite crucible. If, notwithstanding these precautions, a considerable portion of the cadmium volatilizes, the alloy must be again remelted with an excess of cadmium to bring it up to the required percentage.

In modern times certain alloys of gold are also prepared by the galvanic process, and articles showing various colors are now manufactured by this method. It is generally done by immersing the article of gold in a diluted bath of chloride of gold in which is a plate of silver connected with the positive pole of a battery; silver separates upon the gold, a certain alloy being formed which is used as a basis for further coloring. When the desired color has made its appearance, the plate of silver is replaced by one of colored gold, whose color corresponds to the shade the article is to have.

In many factories it is customary to color the finished gold articles, *i*, *e.*, to impart to them, by treatment with agents capable of dissolving copper, a color approaching that of chemically pure gold. By this operation the alloy of gold and copper is decomposed on the surface of the article, the copper being dissolved out. By allowing the surface of the article to remain in contact with the bath for some time the copper is entirely dissolved, a layer of pure gold with its characteristic color remaining behind. By allowing the bath to act for a shorter time only a portion of the copper is dissolved, and, by skilful manipulation, the various shades between red and yellow can be imparted to the articles.

CHAPTER XVIII.

ALLOYS OF PLATINUM AND PLATINUM METALS.

Platinum alloys readily with most metals, and some of these alloys are of technical importance as they offer greater resistance to chemical influences than platinum itself. The ductility of the latter is, as a rule, decreased by other metals, but its hardness is increased, and alloys of a determined color may be prepared from cheaper metals. Pure platinum, as well as its alloys with iridium and palladium, is used in the manufacture of standard weights and scales. The platinum vessels used in chemical laboratories, in the manufacture of sulphuric acid and other chemical products, consist generally of platinum alloyed with one of its allied metals.

The ordinary technically pure commercial platinum contains about 0.1 to 1 per cent. iridium. Chemically pure platinum is as soft and ductile as gold; traces of iridium impart to it the hardness and greater resistance against chemical influences required for most purposes.

Platinum melting only at a very high temperature, a furnace of peculiar construction heated with oxy-hydrogen gas is required for the preparation of the alloys. The melting-points of the latter are, however, frequently so low as to allow of their being melted in ordinary furnaces. In the following we will briefly describe a platinum furnace exhibited by the French government at the Paris Exhibition in 1878, which is used for melting the platinum required in the manufacture of standard meters.

This furnace, or, more correctly, melting apparatus, consists of an oblong bowl of lime with a cavity capable of holding 440 pounds of melted platinum. Upon this bowl

a lid of lime can be lowered by means of a lever mechanism. In this lid are so-called Daniell's cocks, used for ordinary oxy-hydrogen blow-pipes. The products of combustion escape through apertures in the periphery of the bowl. The oxy-hydrogen gas used in this apparatus does not consist of oxygen and hydrogen, but of oxygen and illuminating gas.

For the preparation of platinum alloys on a small scale an apparatus resembling the above in its main features may be used. A bowl holding several pounds of platinum can be fashioned from chalk over a wooden mould, and is, before use, converted into caustic lime by heating to a white heat. An ordinary oxy-hydrogen blowpipe is used, the compressed oxygen and hydrogen being contained in strong vessels, or in bags of strong canvas made gas-proof by several coats of rubber varnish. In preparing alloys of platinum with base metals in such a bowl, it must be taken into consideration that the latter are at once oxidized by the smallest excess of oxygen, and hence care must be had to set the cocks of the oxy-hydrogen blow-pipe so that the flame receives a small excess of hydrogen. In preparing the alloys the quantity of platinum required is first brought into flux, and then the other metals are added all at once through an aperture in the lid of the bowl which otherwise is closed with a lime-plate.

Immediately after the introduction of the metals into the fused platinum, the flame can be modified or in some cases entirely extinguished, the alloys having, as a rule, much lower melting points than platinum. The melted alloy is cast in ingots or cylindrical bars in moulds of lime. The ingots are especially adapted for rolling out into sheet, while the bars are more suitable for wire.

Platinum-iridium alloys.—Heräus treated pure platinum alloyed with only 0.01 per cent. iridium, and with 5 and 10 per cent iridium for forty days with boiling sulphuric acid of 98 per cent. By taking the loss in weight of pure plati-

num = 100, the alloys of platinum 95 and iridium 5 were = 73 and of platinum 90 and iridium 10 = 58, the decrease of the latter being therefore little more than one-half of that of pure platinum. Hence platinum-iridium alloys are better adapted for sulphuric acid concentration apparatus than pure platinum.

Siebert recommends for laboratory use crucibles of an alloy of 70 to 75 parts platinum and 25 to 30 parts iridium. The hardness and solubility in aqua-regia increase with the content of iridium; if the latter is not below 20 per cent., the alloy is almost completely resistant. The alloys take a high polish and with a large content of iridium are somewhat harder than gold of 916 fineness.

Examples of alloys which can be readily worked are as follows:

	I.	II.
Platinum	91.2	92.6 per cent.
Iridium	5.4	7.0 "
Rhodium	3.4	0.4 "

Alloy No. II. can be readily rolled and is suitable for the preparation of patterns.

Meter-rules manufactured for the French government by Johnson & Matthey of London contained 89.41 platinum, 10.17 iridium, 0.17 rhodium, 0.10 ruthenium, and 0.06 iron.

A ductile and malleable alloy of specific gravity 21.614, consists of platinum 80.650, iridium 19.078, rhodium 0.122, ruthenium 0.046, and iron 0.098.

According to Wille the alloy for kilogrammes consists of platinum 89.90, iridium 10.09, rhodium a trace, and iron 0.01.

Platinum-palladium alloys.—With palladium platinum forms a gray alloy. An alloy of platinum with 30 per cent. rhodium is according to Chapius, not attacked by aqua-regia, and after melting can be readily worked.

According to Heräus an alloy of pure platinum with up to 50 per cent. rhodium can be drawn into wire, and an alloy of 90 per cent. platinum and 10 per cent. rhodium is used in Le Chatelier's thermo-electric pyrometer.

Platinum-gold alloys.—The two metals may be alloyed in all proportions, but on account of the refractory nature of the platinum the combination takes place only at a very high temperature. A very small quantity of platinum suffices to change the properties of gold to a considerable extent. With a very small percentage the color becomes sensibly lighter than that of pure gold, and the alloys show a high degree of elasticity, which they nearly lose, however, if the content of platinum exceeds 20 per cent. The melting point of the alloys is very high, and those with 70 per cent. platinum can be fused only in the flame of oxy-hydrogen gas. Alloys containing less platinum may be prepared in a furnace which must, however, be capable of producing the strongest white heat possible. The application of platinum-gold alloys is limited; one containing from 5 to 10 per cent. platinum is used in the form of sheet and wire in the manufacture of artificial sets of teeth.

According to Percy a platinum-gold alloy resists the action of alkalies better than pure platinum.

When platinum-gold alloys are cast in the form of balls in iron moulds, the content of platinum concentrates, on cooling of the alloy, towards the center.

Platinum-gold alloys are used for pyrometric measurements. By taking the melting-point of gold at 1967° F., and that of platinum at 3137° F., then alloys with

950	gold and	50	platinum	melt at	2012° F.
900	"	100	"	"	2066° F.
850	"	150	"	"	2117° F.
800	"	200	"	"	2172° F.
750	"	250	"	"	2228° F.
700	"	300	"	"	2291° F.
600	"	400	"	"	2408° F.
500	"	500	"	"	2525° F.

However, above 2192° F. platinum-gold alloys with more than 15 per cent. platinum cannot be recommended, as they do not melt uniformly, an alloy richer in gold first liquating out.

Platinum-silver alloys.—By an addition of platinum the hardness of silver is increased, its ductility decreased, and its pure white color changed to gray, an alloy containing but a few per cent. of platinum, showing a much darker color than pure silver. The alloys obtained by melting the metals together in suitable proportions, for instance, 1 part platinum and 2 parts silver, are as fusible as 20 carat gold, as ductile and malleable as 18 carat gold, and no more oxidizable than 14 carat gold. Equal weights of platinum and silver yield a hard and brittle alloy with little luster.

White alloys called *Platine au titre*, contain 35 parts platinum and 65 parts silver; or 17½ parts platinum and 82½ parts silver. With an addition of 2 to 3 per cent. copper, these alloys are used for soldering platinum articles.

Such alloys are also used by dentists, for instance, platinum 2 parts, silver 1; *or* platinum 2 parts, silver 1, and palladium 1.

Platinum-gold-silver alloys.—These alloys are used by dentists in the form of fine wires and plates. The silver and gold are first melted, the platinum is then added, and occasionally palladium. Examples of such alloys are:

	Parts.							
	I.	II.	III.	IV.	V.	VI.	VII.	VIII.
Platinum	4	2	9	6	14	10	2	2
Gold	1	1	2	2	4	6	1	—
Silver	1	1	1	1	6	—	—	1
Palladium	—	—	—	—	—	8	—	1

The alloy most suitable for the purpose as regards lightness, elasticity, and color is selected, and pure gold or an alloy of gold and silver used as solder.

Platinor.—The alloy known under this name in commerce has a beautiful golden-yellow color (hence its name) without containing any gold. It consists of varying quantities of

platinum, silver, copper, zinc, and nickel, the variations in the percentage of copper and zinc being very likely due to the fact that the two metals are not used directly, but in the form of brass. The use of the latter has the advantage of making the alloy more homogeneous and preventing, to some extent, the loss of zinc. An alloy with a color closely resembling that of pure gold and quite constant in the air may be made as follows: Melt 1 part of silver with 5 of copper, add to the melted mass 2 parts of brass, then 1 of nickel, and, after raising the temperature to the highest point the furnace is capable of producing, 2 parts of platinum, which is best used in the form of a very fine powder, the so-called platinum-black.

Platinum-bronze.—This alloy deserves attention, it possessing properties not to be found to the same extent in other alloys, and besides it is not very expensive. Platinum-bronzes are indifferent to the action of air and water, and, once polished, retain their bright luster for a long time. Up to the present time they have only been used for table-ware and articles of luxury, and occasionally, on account of their sonorousness, for bells. Besides tin, platinum-bronze always contains platinum and, some compositions, a certain quantity of silver, which, however, can be replaced by a corresponding quantity of brass without impairing the resistance against atmospheric influences. The following table gives the composition of some varieties of platinum-bronze:

Uses.	Parts.				
	Nickel.	Platinum.	Tin.	Silver.	Brass.
For table utensils	100	1	10	—	—
For bells.....	100	1	20	2	—
For articles of luxury.....	100	0.5	15	—	—
For tubes for spy-glasses..	100	20	20	—	—
For ornaments.....	60	10	—	—	120

Alloys of platinum with the base metals.—Among the alloys of platinum with the base metals only those with copper and iron are of importance. The other metals also form alloys with platinum, which, however, are not suitable for technical purposes. The alloys with iron are also of secondary interest, since platinum-iron and platinum-steel have not found the general application in the industries which was at one time prophesied by many. It may, however, be said that a certain addition of platinum imparts to steel many excellent properties, an alloy consisting of 1 part of platinum and 70 of steel being, for instance, on account of its great hardness, very suitable for the manufacture of cutting tools. For knives with especially sharp edges, an alloy containing only one-half per cent. of platinum is claimed to be the most suitable.

With pure iron, platinum forms a steel-gray mass very difficult to fuse, and so hard as to be scarcely scratched by the best file. Berthier tried alloys made of 1 part platinum with from 4 to 10 parts of iron. The fracture of the alloy was gray and granular, and it was possible to flatten the metal with a hammer before breaking it.

Alloys of platinum and copper.—These alloys, possessing with great ductility and toughness a very beautiful color, can be advantageously used for some technical purposes. The color of the copper is modified by the presence of a comparatively small quantity of platinum, copper containing but 4 per cent. of it showing a rose color, which, in the presence of more platinum, soon changes to golden-yellow.

The alloys of copper with platinum are very ductile, malleable, and easily worked. By adding zinc, a mixture of metals is obtained which, as regards color and durability of luster, is equal to gold, and, for this reason, is used in the manufacture of ornaments. The properties of the alloys vary very much according to the quantity of metals they contain, and, hence, they are adapted for many technical purposes.

Golden-yellow alloys of platinum and copper.—Alloys so composed that their color approaches that of pure gold are suitable for the manufacture of jewelry and other ornaments, and as regards the price of metals can be prepared for about twice the cost of silver. With an equally beautiful color they surpass gold, on account of their much lower price, and, especially, their durability.

The composition of the alloys used in the manufacture of ornaments varies within very wide limits. The following are, however, the most important:

	Parts.			
	I.	II.	III.	IV.
Platinum	2	20	7	3
Copper	5	—	16	13
Zinc	—	—	1	—
Silver	1	20	—	—
Brass	2	240	—	—
Nickel	1	120	—	—

The alloy No. IV., which is known as Cooper's gold, is especially adapted for ornamental articles, it having a color which cannot be distinguished from that of 18 carat gold, even by a close comparison. It can be drawn out to the finest wire, and rolled out to very thin sheet.

Other alloys suitable for ornaments, on account of their gold-like appearance, are composed of—

	Parts.			
	I.	II.	III.	IV.
Platinum	15	16	7	6
Copper	10	7	16	26
Zinc	1	1	1	—

The success in preparing these alloys depends, however, on using metals entirely free from iron, experiments having shown that the $\frac{8}{1000}$ part of the weight of the alloy of iron suffices to render it sensibly brittle. If any one of the constituent metals contains iron, the alloy, though showing a

beautiful color, will be too hard, and besides so brittle as to make it impossible to draw it out into fine wire or roll it out to thin sheet.

Cooper has thoroughly examined the properties of platinum alloys, and to his researches we are indebted for some important compositions which he has termed mirror-metal and pen-metal, they being especially suitable for these purposes.

Cooper's mirror-metal.—Copper 35 parts, platinum 6, zinc 2, tin 16.5, arsenic 1. This alloy being entirely indifferent to the action of the weather, and taking a beautiful polish on account of its hardness, is especially adapted for the manufacture of mirrors for optical instruments.

Cooper's pen-metal.—The preceding alloy is also very suitable for the manufacture of pens, but is too expensive to compete successfully with steel. An alloy frequently used for the preparation of pen-metal consists of: Copper 1 or 12 parts, platinum 4 or 50, silver 3 or 36.

Their great hardness and resistance against atmospheric influences make Cooper's pen alloys very suitable for the manufacture of mathematical and other instruments of precision. It can, for instance, scarcely be calculated how long a chronometer, whose train of wheels is constructed of such an alloy, can run before it shows any irregularity attributable to wear.

Palladium alloys.—Palladium occurs associated with platinum, and is obtained as a by-product in refining platinum. Pure palladium is but little used. It is sometimes employed in the preparation of mirrors by the galvanic process, or of semicircular protractors for fine mathematical instruments.

The pure metal is, however, more frequently used in the preparation of alloys which are chiefly employed in dentistry and in the manufacture of fine watches. The most important of these alloys are the silver alloys and the so-called palladium bearing-metal.

Alloys of palladium and silver.—This alloy, which is almost exclusively used for dental purposes, consists of 9 parts of palladium and 1 part of silver. It does not oxidize, and is, therefore, very suitable for plates for artificial teeth. The following alloy is still more frequently used: Platinum 10 parts, palladium 8, gold 6.

Palladium-bearing metal.—This alloy is uncommonly hard, and is said to produce less friction upon arbors of hard steel than the bearings of jewels generally used for fine watches. This alloy has the following composition: Palladium 24 parts, gold 72, silver 44, copper 92.

Palladium alloys.

	I.	II.
Palladium	20	6
Gold	80	18
Silver	—	11
Copper	—	13

Alloy No. I. is white, hard as steel, unchangeable in the air, and suitable for dental purposes. Alloy No. II. is red brown, hard, has a very fine grain, and is especially suitable for pivot bearings of watch-works.

The alloys of the other platinum metals are but little used, particularly on account of their rarity and costliness. The alloys of platinum and iridium are only used for special scientific purposes, for instance, for standard scales, etc. Iridium as well as rhodium possessess the property of imparting great hardness to steel, but the rhodium and iridium steel found in commerce contain, in many cases, not a trace of either. The alloy of iridium with osmium is distinguished by great hardness and resistance, and has, therefore, been recommended for pivots, for fine instruments, and points for ships' compasses.

Alloys for watch manufacturers.—For the manufacture of parts of watches which are to be insensible to magnetism, the following very tough and hard alloys may be recommended:

	I.	II.	III.	IV.	V.	VI.	VII.
Platinum	62.75	62.75	62.75	54.32	0.5	0.5	—
Copper	18.00	16.20	16.20	16.00	18.5	18.5	25.0
Nickel	18.00	18.00	16.50	24.70	—	2.0	1.0
Cadmium	1.25	1.25	1.25	1.25	—	—	—
Cobalt	—	—	1.50	1.96	—	—	—
Tungsten	—	1.80	1.80	1.77	—	—	—
Palladium	—	—	—	—	72.0	72.0	70.0
Silver	—	—	—	—	6.5	7.0	4.0
Rhodium	—	—	—	—	1.0	—	—
Gold	—	—	—	—	1.5	—	—

Phosphor-iridium.—For preparing larger pieces of iridium than found in nature for making points for stylographic pens, Mr. John Holland, of Cincinnati, has devised the following ingenious process: The ore is heated in a Hessian crucible to a white heat, and, after adding phosphorus, the heating is continued for a few minutes. In this manner a perfect fusion of the metal is obtained, which can be poured out and cast into any desired shape. The material is about as hard as the natural grains of iridium, and, in fact, seems to have all the properties of the metal itself.

Phosphor-iridium, as this metal may be called, possesses some very remarkable properties. It is as hard, if not harder, than iridosmine, from which it is prepared. It is somewhat lighter, owing to its percentage of phosphorus and increase of volume. It is homogeneous and easy to polish, and forms some alloys impossible to prepare in any other manner. It combines with small quantities of silver and forms with it the most flexible and resisting alloy of silver. With gold or tin no alloy has thus far been obtained. Added in small quantities to copper it furnishes a metal possessing very small resistance to friction, and is especially adapted for articles subjected to great pressure. This alloy seems to possess more than any other metal the power of retaining lubricants. With iron, nickel, cobalt, and platinum, phosphor-iridium forms combinations in all proportions, which are of great importance. With iron an alloy is obtained which retains the properties

of phosphor-iridium, although its hardness decreases with a larger addition of iron. The alloy is slightly magnetic, and is not attacked by acids and alkalies, and the best file produces no effect upon it, even if it contains as much as 50 per cent. of iron. With more than 50 per cent. of iron the power of resistance decreases gradually, and the nature of the metal approaches that of iron.

CHAPTER XIX.

ALLOYS OF MERCURY AND OTHER METALS OR AMALGAMS.

MERCURY, as is well known, is the only metal which is liquid at an ordinary temperature. It solidifies at—40° F., forming a ductile, malleable mass, and boils at 662° F., forming a colorless vapor; it volatilizes, however, even at ordinary temperatures. With other metals it forms alloys which are called amalgams. According to Thomas Aquino and Libadius the term amalgam is derived from the Greek μάλαγμα (softening body), and according to others from the Arabic word Algamals. The properties of the amalgams vary very much according to the metals used. In most cases they are at first liquid and after some time acquire a crystallized form, the mercury in excess being thereby eliminated.

The amalgams offer an excellent means of studying the behavior of the metals toward each other, the examination being facilitated by the low temperature at which these combinations are formed. If a metal be dissolved in mercury, and the latter be present in excess, a crystalline combination will in a short time be observed to separate from the originally liquid mass. This crystalline combination forms the actual amalgam, and is composed of proportions which can be expressed according to determined atomic weights, and can be readily obtained by removing the excess of mercury by pressure.

Many amalgams require considerable time to pass into the crystalline state, and are at first so soft that they can be kneaded in the hand like wax, but harden completely in

time. They are especially adapted and much used for filling hollow teeth.

Before the action of the galvanic current upon solutions of metals was known, amalgams were of great importance for gilding and silvering, which was effected by coating the article to be gilt or silvered with the amalgam and volatilizing the mercury by the application of heat, whereby the gold and silver remained behind as a coherent coat (fire gilding).

Mercury unites readily with lead, zinc, tin, bismuth, cadmium, copper, gold, silver, magnesium, potassium and sodium, while iron, nickel, cobalt, manganese and platinum in the compact state combine with it with difficulty.

Though the amalgams are of considerable theoretical interest and of great importance for a general knowledge of alloys, only a limited number of them are used in the industries, which will be somewhat more closely described in the following:

Gold amalgam.—Gold and mercury alloy freely, and the amalgam can be prepared by the direct union of the two metals. If the gold to be used has been obtained by the chemical process (by the reduction of salts of gold) it dissolves with difficulty in the mercury, it being in a finely divided state, and the finer particles are apt to float upon the surface of the mercury. If, however, the gold is reduced in the form of larger crystals, the solution takes place in a comparatively short time. Such small gold crystals can be readily obtained by dissolving chloride of gold in amyl alcohol and heating the solution to boiling, whereby the gold is separated in the form of very small, lustrous crystals.

In gaining gold from auriferous sand, gold amalgam is prepared in large masses, and by subsequent heating in iron retorts the combination is destroyed, the mercury volatilizing, while the pure gold remains behind. Gold forms with mercury a chemical combination of the formula Au_4Hg,

showing great tendency towards crystallization, which, in preparing the amalgam, must be prevented as much as possible, it being difficult to apply a crystalline amalgam to the articles to be gilded.

An amalgam suitable for fire gilding is best prepared as follows: Heat in a graphite crucible, rubbed inside with chalk to prevent adhesion, the gold to be alloyed, to a red heat. It is not absolutely necessary to use chemically pure gold, but it should be at least 22 carat fine, and preferably alloyed with silver instead of copper. Gold amalgam containing copper becomes stone hard in a short time, and a small content of it impairs its uniform application to the metals to be gilded. It is best to use the gold in the form of thin sheets, which is cut into small pieces by means of scissors, and brought into the crucible. When the gold is heated to a red heat, introduce about the eighth or ninth part of the weight of the gold of mercury previously heated to boiling. Stir constantly with an iron rod, and after a few minutes remove the crucible from the fire. If the finished amalgam were allowed to cool in the crucible, it would become strongly crystalline and be unsuitable for fire gilding. To prevent this it is at once poured into a larger vessel cooled on the outside by water. By keeping this amalgam for some time, crystallization takes place nevertheless, the amalgam separating from the mercury in excess, and it is therefore advisable to prepare it fresh a short time before use. Crystalline amalgam can be restored by heating it in a crucible with an excess of mercury.

Gold-amalgam containing silver gives a green gilding and as this color is frequently desired argentiferous gold is used in preparing the amalgam. The color may be intensified by the application of a mass consisting of 17 parts saltpeter, 14 parts sal ammoniac and 2 parts alum, and heating.

In preparing the amalgam, as well as in using it for gilding, a wind-furnace connected with a well-drawing chimney

should be used, as otherwise the vapors evolved from the mercury exert an injurious effect upon the health of the workmen.

A native gold amalgam containing 39.02 to 41.63 per cent. gold and 60.98 to 58.37 per cent. mercury is found in California. It has the formula Au_2Hg_2.

Silver amalgam.—The properties of silver amalgam are nearly the same in most respects as those of gold amalgam, it having, however, a still greater tendency towards crystallization. Only pure silver can be used for its preparation, a content of copper producing the same injurious effect as in gold amalgam. Silver amalgam is best prepared by using pulverulent silver obtained by the reduction of silver solution. It may be prepared by bringing a solution of nitrate of silver in 10 to 15 parts of water into a bottle, adding a few small pieces of sheet zinc and vigorously shaking a few minutes. The silver separating in the form of a very fine black-gray powder need only be washed and dried to be suitable for the preparation of amalgam. This finely divided powder can be directly dissolved in the mercury, though it requires some time. The object is more quickly attained by heating the mercury nearly to boiling in a crucible, then throwing in the pulverulent silver and quickly combining the mass by vigorous stirring with an iron rod.

Silver amalgam can also be prepared without the use of heat, it being only necessary to compound a concentrated solution of nitrate of silver (1 part of nitrate of silver in 3 of distilled water) with four times the quantity of mercury and combine the liquids by shaking. The silver is reduced from the nitrate by the mercury and dissolves immediately in the excess of it. If the amalgam is to be used for fire-silvering, the presence of the small quantity of nitrate of mercury adhering to it is of no consequence, and it can be at once applied.

Fire-gilding.—Fire-gilding, as well as fire-silvering, is always effected with a pure amalgam, *i. e.*, such as is freed

as much as possible from an excess of mercury. For this purpose the amalgam is tied in a bag of strong chamois leather and subjected to a gradually increasing pressure, whereby the mercury is forced through the pores of the leather while the amalgam remains in the bag. The pressed-out mercury contains a considerable quantity of gold or silver in solution, and is used in the preparation of fresh amalgam.

Fire-gilding as well as silvering is, of course, only applicable to articles of metals which, without melting, will stand a temperature near that of the boiling point of mercury. The amalgam adhering only to absolutely bright metals, the articles before gilding are subjected to a preparatory operation. This consists in heating them to a glowing heat, whereby the grease, dust, etc., adhering to the surface are burnt, and the metal becomes covered with a layer of oxide. The articles are then dipped in a mixture of 3 parts of nitric acid and 1 of sulphuric acid, whereby the oxide is rapidly dissolved and the metal acquires a bright surface. Articles to be heavily gilded must remain for some time in the acid mixture, a rougher surface being required for the adherence of a larger quantity of amalgam.

The pickled articles are then rinsed in water without touching them with the hands, and, to prevent oxidation, placed in water until they are to be *amalgamated*, which consists in covering the bright articles with a layer of metallic mercury. This so-called amalgamating water is prepared by dissolving 100 parts by weight of mercury in 110 parts by weight of strong nitric acid, and compounding the solution with 25 parts by weight of water. This amalgamating water is applied to the metals by mean of a brush of fine brass wire. By the action of the metal upon the mercury salt the latter is reduced to metallic mercury in the form of very small drops, whereby the articles acquire a white color.

The articles being thoroughly amalgamated, the amalgam

is quickly and uniformly applied with a stiff scratch-brush and the articles placed upon glowing coals, whereby the mercury vaporizes while the gold or silver remains behind in a coherent layer. While heating the articles must, however, be frequently taken out and defective places provided with amalgam. This process is very injurious to health; the mercury volatilized by the heat insinuates itself into the body of the workman notwithstanding the greatest care, and those who are so fortunate as to escape for a time absolute disease are constantly liable to salivation from its effects. Though fire-gilding is the most durable, it is more and more abandoned and electro-plating substituted for it.

Many articles are not finished by one gilding, and have to be subjected to the same process twice and frequently three times, whereby the layer of gold becomes, of course, thicker. By suitable treatment during the heating and by burning off the so-called gilder's wax, various shades can be given to the gilding. But, as these operations belong to another branch of industry, we cannot enter upon a further description of them.

Copper amalgam.—On account of its peculiar properties copper amalgam finds quite an extensive use in several branches of industry, an amalgam of copper, tin, lead and antimony serving for the production of axle bearings.

It crystallizes with great ease, and on solidifying becomes so hard that it can be polished like gold. It can also be worked under the hammer and between rolls, be stamped, and retains its metallic luster for some time on exposure to the air, but tarnishes quickly and turns black on being brought in contact with air containing sulphuretted hydrogen. A peculiar property of amalgam of copper is that it becomes soft on being placed in boiling water, and so flexible that it can be used for molding the most delicate articles. In a few hours it again solidifies to a fine-grained mass which is quite malleable.

Copper amalgam, on account of its peculiar properties,

was formerly recommended for filling hollow teeth, but is no longer used for that purpose, there being other amalgams just as suitable and free from poisonous copper. An important application of copper amalgam is for cementing metal, it being only necessary to apply it to the metals to be cemented, which must be bright and previously heated to from 176° to 194° F., and press them together; they will be joined as tightly as if soldered.

Many directions have been given for preparing amalgam of copper, but it is effected with the greatest ease as follows: Place strips of zinc in a solution of sulphate of copper and shake vigorously. The copper thus obtained in the form of a delicate powder is washed, and, while still moist, treated in a rubbing-dish with a solution of mercurous nitrate. Hot water is then poured over the copper, the dish kept warm, and the mercury added. The contents of the dish are then kneaded with a pestle until the pulverulent copper combines with the mercury to a plastic mass; the longer the kneading is continued the more homogeneous the mass will be. The best proportions to use are 3 parts of copper and 7 of mercury.

When the amalgam has the proper consistency, the water is poured off and the soft amalgam moulded in the shape in which it is to be preserved. For the purpose of cementing it is recommended to roll it into small cylinders about ⅛ inch in diameter and ¾ to 1½ inches long.

A composition of 25 parts of copper in fine powder, obtained by precipitation from solutions of the oxide by hydrogen, or of the sulphate by zinc, washed with sulphuric acid and amalgamated with 7 parts of mercury, after being well washed and dried, is moderately hard, takes a good polish, and makes a fine solder for low temperatures. It will adhere to glass.

An imitation of gold, *known as Vienna metallic cement*, which, on account of its golden-yellow color and capability for taking a fine polish, is suitable for the manufacture of

cheap jewelry, consists of copper 86.4 parts. mercury 13.6. The color of the alloy being, however, very easily affected by sulphuretted hydrogen, it is recommended to provide the articles with a thin coating of pure gold by the galvanic method.

Dronier's malleable bronze is made by adding 1 per cent. of mercury to the tin when hot, and this amalgam is carefully introduced into the melted copper.

Tin-amalgam. This amalgam was formerly of much greater importance for the manufacture of mirrors and looking-glasses than at present, when mirrors coated with a thin layer of silver surpass those coated with amalgam in beauty and cheapness. The great affinity of tin for mercury renders the preparation of the amalgam easy; all that is necessary being to combine the tin, best in the form of fine shavings, or foil, with the mercury. According to the quantity of mercury rubbed together with the tin, an amalgam solidifying in a shorter or longer time is obtained.

Tin-amalgam for filling teeth.—This amalgam is prepared by intimately rubbing together 1 part of tin with 4 of mercury, removing the excess of mercury by pressing in a leather bag, and kneading or rubbing for some time. It is obtained in a flexible mass which hardens in a few days.

Amalgam for mirrors and looking-glasses.—The amalgam which serves for silvering mirrors is a complete saturation of the two metals. It is, however, not prepared by itself, but directly upon the plate of glass which is to form the mirror. The operation is as follows: The glass plate having been thoroughly cleansed from all grease and dirt with putty-powder and wood ash, the workman proceeds to lay a sheet of tin foil of larger dimensions than the plate to be silvered smoothly upon the silvering table, pressing out with a cloth-dabber all wrinkles and places likely to form air-bubbles. A small quantity of mercury is then poured upon it and uniformly distributed by means of a fine woolen cloth. When the surface is uniformly covered more mercury

is added so as to attain a height of 2 or 3 lines; the coating of oxide is removed with a wooden rod and a brilliant surface produced. The plate of glass is then pushed slowly forward from the side with the longest edge foremost, and dipping below the surface of the mercury so as completely to exclude the air. In this way the glass is brought into contact with the metals and a brilliant surface produced. The plate may now be said to be floating on a bed of mercury. To get rid of the excess of metal the mirror is loaded with weights and the table inclined 10° or 12°, when the excess of mercury drains off. A further portion is got rid of by setting the plate up on edge, and in the course of three or four weeks a dry, permanent coating of tin amalgam is left upon the plate.

If curved glass plates are to be converted into mirrors, the amalgam is prepared by itself, and after spreading it as uniformly as possible upon the glass the latter is heated until the amalgam melts.

This method of silvering has many objections: The vapor of mercury is poisonous to the workmen; the plates are liable to fracture from the heavy load placed upon them, and when set up on edge drops of mercury sometimes trickle down, carrying the amalgam with them, thus rendering it necessary to resilver the whole mirror. Moreover, the amalgam is liable to spoil by crystallization or carriage. For these reasons this process has been almost entirely abandoned and that of silvering by precipitation substituted for it.

Amalgam for coating rubbers of electric machines.—This amalgam, known as Kienmayer's consists of zinc 1 part, tin 1, and mercury 2. It is prepared by bringing the metals in the form of fine shavings free from oxide into a previously heated iron mortar and rubbing it with the mercury to a homogeneous mass. The amalgam has a tendency to become crystalline, even if kept in well-stoppered glass-vessels, but it can be readily pulverized and if

mixed with a very small quantity of tallow does excellent service. By this method of preparation the disadvantage of the otherwise unadvoidable melting of the solid metals is avoided.

Singer's amalgam for the same purpose consists of tin 1 part, zinc 2, and mercury 3½ to 6. Böttger melts in an iron spoon 2 parts zinc and carefully adds, with constant stirring, 1 part mercury.

Musiv silver.—This is a combination of tin 3 parts, bismuth 3 and mercury 1½, and serves for the spurious silvering of brass and copper, the amalgam mixed with 6 parts bone ash being applied by rubbing the articles with it. For silvering paste-board, wood, paper, etc., the mass is triturated with white of egg, gum solution, glue-water, or varnish and applied to the articles.

Amalgam for tinning.—Small iron articles, pins, etc., may be tinned by pickling them in an acid, dipping in tin amalgam made liquid by means of hot water, blanching, washing, drying with coarse bran, and polishing.

Zinc amalgam.—Zinc unites with mercury at the ordinary temperature, but more readily at a higher one. Triturate 1 part zinc filings, 4 parts chloride of mercury and 2 parts of water, adding a few drops of mercury, *or*, mix two parts mercury with two parts zinc melted in an iron spoon, stirring constantly with a clay rod. The very brittle amalgam is powdered, triturated with tallow, and may be used for coating rubbers of electric machines.

Zinc amalgam is electrolytically prepared by connecting by means of a wire the zinc cylinder of a Daniell cell with a small quantity of mercury covered by a zinc sulphate solution, a zinc wire serving as anode of the battery dipping into the solution.

For the *amalgamation of zinc for voltaic cells* brush the zinc with ammonium zinc chloride at 450° to 500° F. and then apply the mercury, when combination will immediately and completely take place.

The zinc may also be pickled in sulphuric acid and the mercury applied with a metallic scratch-brush dipped in dilute sulphuric acid.

The zinc elements may also be immersed in a fluid prepared by dissolving 7 ozs. of mercury in 35 ozs. of aqua-regia and 39 ozs. of hydrochloric acid. With about 1 quart of this fluid 150 elements can be amalgamated.

Spurious gilding of copper by the formation of brass is produced by boiling the copper article in a mixture of tartar, hydrochloric acid and zinc amalgam (1 part zinc and 12 parts mercury).

Cadmium-amalgam.—Cadmium readily combines with mercury to an amalgam which easily becomes crystalline. For the preparation of the actual cadmium-amalgam, whose composition is Cd_5Hg_8, proceed in the same manner as already described for other amalgams. Heat the mercury nearly to boiling in a crucible and introduce the cadmium in the form of thin sheet. Cadmium amalgam remains soft for some time and becomes crystalline only after a considerable period. The mass obtained by heating is, therefore, allowed to stand in the crucible until the excess of mercury separates out, or it can be separated in the ordinary manner by pressing in a leather bag.

Pure cadmium-amalgam forms a tin-white or silver-white mass which softens on being moderately heated and can be kneaded like wax. It is used for filling hollow teeth, either by itself or compounded with other metals, which make it still better for the purpose. An addition of tin or bismuth makes it more pliant in the heat, and for this reason the mass used for filling teeth is at present frequently composed of amalgams containing several metals. A few such compositions are given in the following. Those containing lead are, however, not recommended, as lead has poisonous properties and is attacked even in the form of an amalgam by organic acids:

Amalgams for filling teeth.

	Parts.				
	I.	II.	III.	IV.	V.
Cadmium	25.99	21.74	1	1 to 2	3
Mercury	74.01	78.26	—	—	—
Tin	—	—	2	2	4
Lead	—	—	—	7 to 8	15

Amalgam No. I. corresponds to the centesimal composition of the above-mentioned combination of cadmium and mercury, and is well adapted for filling teeth, it acquiring in time such hardness that it can be worked with the lathe or file, and, of course, becomes hard in the mouth. Cadmium-amalgams being very ductile can, moreover, be used for many other purposes. An amalgam of equal parts of cadmium and mercury is extremely plastic and can be stretched under the hammer like pure gold. It is silver-white and constant in the air.

Evans's metallic cement.—This alloy is obtained by dissolving a cadmium-amalgam consisting of 25.99 parts of cadmium and 74.01 of mercury in an excess of mercury, slightly pressing the solution in a leather bag and thoroughly kneading. By kneading, especially if the amalgam be previously heated to about 97° F., Evans's metallic cement is rendered very plastic, and like softened wax can can be brought into any desired form. On cooling it acquires considerable hardness, which is, however, not equal to that of pure cadmium-amalgam.

Amalgams of the "fusible alloys."—The fusible alloys already mentioned in speaking of the alloys of cadmium and bismuth possess the property of melting in an amalgamated state at a still lower temperature than by themselves. By adding a suitable quantity of mercury to them they can be converted into masses well adapted for filling teeth or for cementing metals.

Amalgam of Lipowitz's metal.—This amalgam is prepared as follows: Melt in a dish cadmium 3 parts, tin 4,

bismuth 15, and lead 8, and add to the melted alloy, mercury 2 parts, previously heated to about 212° F. Amalgamation takes place readily and smoothly. After the introduction of the mercury the dish is immediately taken from the fire and the liquid mass stirred until it solidifies. While Lipowitz's alloy becomes soft at 140° F. and melts at 158° F., the amalgam melts at about 143.5° F. It is very suitable for the production of impressions of objects of natural history, direct impressions of leaves and other delicate parts of plants being obtained, which, as regards sharpness, are equal to the best plaster of Paris casts, and, on account of the silver-white color, fine luster, and constancy of the amalgam, present a very neat appearance. The amalgam can also be used for the manufacture of small hollow statuettes and busts, which can be readily gilt or bronzed by the galvanic process.

The manufacture of small statuettes is readily effected by preparing a hollow mould of plaster of Paris, and, after uniformly heating it to about 140° F., pouring in the melted amalgam. The mould is then swung to and fro, this being continued until the amalgam is solidified. After cooling the mould is taken apart and the seams trimmed with a sharp knife. Some experience being required to swing the mould so that all parts are uniformly moistened with the amalgam, it may happen that defective casts are at first obtained; in such case the amalgam is simply remelted and the operation commenced anew. With some skill the operator will soon succeed in applying a uniform layer to the sides of the mould and preparing casts with very thin sides. The operation may also be modified by placing the mould upon a rapidly revolving disk and pouring in the melted amalgam in a thin stream. By the centrifugal force developed the melted metal is hurled against the sides of the mould, and in this manner statuettes of considerable size can be cast.

Iron-amalgam.—Iron and mercury do not unite directly

and can only be combined by means of a third metal, etc., though it is sometimes doubtful whether an actual amalgam is formed. According to Böttger, the amalgam may be prepared by triturating 1 part finely divided iron with 2 parts mercuric chloride and 2 parts water, and adding a few drops of mercury.

Gulielmo triturates in a porcelain dish 4½ parts pulverized ferrous sulphate and 1 part pulverized zinc with 12 parts water of 140° to 167° F., and frees the iron amalgam which after some time is formed by washing from the rest.

According to Joule a crystalline mass of lustrous iron amalgam, especially beautiful if composed of 100 parts mercury and 47.5 parts iron, is formed by connecting by means of wire the zinc cylinder of a Daniell cell with a small quantity of mercury by a ferrous sulphate solution, an iron wire dipping into the latter serving as anode of the battery. According to the duration and intensity of the current, the amalgams are solid or liquid, crystalline, and with metallic luster with different contents of iron (0.143 to 103.2 iron to 100 mercury). The amalgams are magnetic and when subjected to violent shocks the iron is superficially separated in pulverulent form. When heated to the boiling point of mercury, ferric oxide remains behind, sparks being emitted. When submerged under water the amalgam becomes in a few days covered with rust and, on shaking the vessel, is almost immediately disintegrated, the iron floating in the form of a black powder upon the mercury.

Iron articles to be uniformly gilded with gold amalgam are frequently first coated with a layer of mercury by boiling them after thorough cleaning, in a porcelain or clay vessel in a mixture of mercury 12 parts, zinc 1 part, ferrous sulphate 2 parts, water 12 parts and hydrochloric acid 1½ parts. A mirror-bright surface is thus obtained to which the gold amalgam can be uniformly applied.

Bismuth-amalgam.—By introducing mercury into melted

bismuth a combination of the two metals is readily effected. The resulting amalgam being very thinly fluid can be advantageously used for filling out very delicate moulds. Other amalgams are also rendered more thinly fluid by an addition of bismuth-amalgam, a few examples of which have already been given under cadmium-amalgams, and such combinations, being cheaper than pure bismuth-amalgam, are frequently used.

Bismuth-amalgam can be used for nearly all purposes for which cadmium-amalgams are employed. On account of their luster, which is at least equal to that of silver, they are preferred for certain purposes, such as for silvering glass globes and the preparation of anatomical specimens.

Amalgams for silvering glass globes, etc.—Glass globes can be readily silvered by either of the following compositions:

	Parts.		
	I.	II.	III.
Bismuth	2	2	2
Lead	2	2	2
Tin	2	2	2
Mercury	2	4	18

First melt the lead and tin and then add the bismuth. After removing the dross pour the mercury into the compound and stir vigorously. Leaves of Dutch gold are sometimes introduced into the mixtures according to the color to be imparted to the globes. For silvering the globes heat them carefully to the melting point of the amalgam. Then pour a small quantity of the amalgam into the cavity of the globe and swing it to and fro until its entire surface appears covered.

Amalgam of bismuth for anatomical preparations.—Colored wax was formerly exclusively used by anatomists for injecting vessels. A bismuth-amalgam, being of a silvery-white color, is, however, preferable, and by becoming hard on cooling contributes essentially to the solidity of the

preparation. The amalgam used for the purpose melts at 169° F. and remains liquid at 140° F., the latter property rendering its use especially suitable for larger preparations. It is composed of: Bismuth 10 parts, lead 3.2, tin 3.5, mercury 2. For use, heat the amalgam in a dish in a water-bath to 212° F., which insures it being forced by the injection-pump into the finest ramifications of the vessels.

Metallic pencils may be prepared from an alloy of 70 parts lead, 90 parts bismuth and 8 parts mercury. The lead and bismuth are first melted, and the melt allowed to cool somewhat when the mercury is added, stirring constantly. If necessary the whole is again heated and the alloy cast in moulds.

Pholin's silver-like alloy consists of 19.23 per cent. bismuth, 76.90 tin, 3.84 copper and a trace of mercury.

Sodium-amalgam.—By itself this amalgam is not used, it quickly decomposing on exposure to the air into caustic soda and mercury. It can, however, be used in the preparation of many amalgams which cannot be made by the direct method. By bringing, for instance, amalgam of sodium together with a solution of metallic chloride, the respective metal is generally separated from the chlorine combination by the sodium, and the moment it is liberated unites with the mercury to an amalgam while the sodium combines with the chlorine. The presence of a very small quantity of sodium amalgam exerts, moreover, a very favorable effect upon the formation of amalgams, and by its use in the process of amalgamation for gaining gold and silver considerable time is saved and the amalgamation becomes more complete.

Sodium and mercury unite at the ordinary temperature to an amalgam which in the proportion of 1 part sodium to 80 parts or more of mercury is soft to liquid, but solid with a larger content of sodium. For the preparation of an amalgam as rich in sodium as possible, 35 ozs. of mercury are heated in an iron dish to 300° F. and 1 oz. of sodium

in coarser pieces is in rapid succession introduced, the sodium pieces being pressed beneath the mercury by means of a rod. Vigorous heating accompanied by fire phenomena takes place, vapors of mercury being at the same time evolved. After cooling the amalgam congeals to a solid brittle mass. It has to be kept protected from moisture.

Rosenfeld* uses for the preparation of the amalgam a crucible with a perforated lid. The aperture in the lid is closed by a well-fitting cork and in the latter is secured a pointed wire reaching to the bottom of the crucible. The total quantity of sodium in one piece is fastened to the wire and dips into a mixture of 1 part amyl alcohol and 9 parts petroleum. When the sodium has acquired a pure silver-white color, it is taken from the fluid and brought into the crucible containing the mercury. The combination of the two metals takes place instantaneously with the emission of a peculiar hissing noise and the appearance of fire. However, as the crucible is at the moment of reaction closed with the lid, but little mercury vapor passes into the air.

Potassium-amalgam is obtained by the introduction of potassium into heated mercury, the air being as much as possible excluded, or by pressing the freshly cut surface of the metal upon mercury, vigorous heating taking place thereby, and an amalgam is formed which become rigid if it contains over 3 per cent. potassium.

By introducing 3 per cent. sodium-amalgam into potash lye a crystallizing combination $Hg_{24}K_2$ is formed in the shape of hard lustrous cubes with octahedron and dodecahedron faces. The cubes when heated to 824° F. leave behind crystalline HgK_2 which spontaneously ignites in the air. The amalgam decomposes slowly in moist air and under water, and, like sodium-amalgam, may be used for amalgamating iron and platinum, as well as in the amalga-

* Berichte der chemischen Gesellschaft, 24, 1659.

mation of silver and gold ores, the amalgam taking up gold and silver with greater ease than mercury.

Nickel-amalgam is formed in the shape of a kneadable mass by rubbing together concentrated nickel chloride solution and an amalgam formed from 1 part sodium and 99 parts mercury, and treating the nickel amalgam thus formed with water until the latter runs off clear. It may also be formed by the addition of mercury to nickel sulphate solution.

Platinum amalgam. A thickly-fluid lead-gray mass is obtained by triturating spongy platinum with heated mercury, or by introducing sodium amalgam into a platinic chloride solution.

Joule obtained an amalgam of a doughy consistency by allowing mercury to remain for a longer time in platinic chloride solution. After being pressed the amalgam contained Hg_2Pt.

By boiling, under exclusion of air, thin platinum sheet in mercury, the former is attacked by the latter and the greater portion of the platinum appears to be suspended in the form of fine black dust in the mercury. If this dust is forced upwards by a current of air and the mercury is isolated, only an inconsiderable quantity of platinum remains behind.

Makenzie's amalgam.—This amalgam, which is solid at an ordinary temperature and becomes liquid by simple friction, may be prepared as follows: Melt 2 parts of bismuth and 4 of lead in separate crucibles, then throw the melted metals into two other crucibles, each containing 1 part of mercury. When cold these alloys or amalgams are solid, but will melt when rubbed one against the other.

CHAPTER XX.

MISCELLANEOUS ALLOYS.

Mixture especially adapted for serving as a protective cover in remelting alloys.—This mixture is composed of borax, calcined soda, calcined alum and fluorspar, each 1 part.

Alloy for spoons.—A beautiful alloy closely resembling silver is obtained by melting together 50 parts of copper, 25 of nickel, and 25 of zinc.

Alloy resembling German silver consists of copper 58 parts, zinc 27, nickel 12, tin 2, aluminium 0.5, and bismuth 0.5. The separate metals are first melted by themselves and then combined by vigorous stirring. This metal retains its polish for a long time.

Alloy resembling silver.—Copper 70 parts, manganese 30, zinc 20 to 25.

Non-oxidizable alloy.—Iron 10 parts, nickel 36, copper 18, tin 18, zinc 18. This metal has a white color, with a slightly reddish tinge.

Calin.—This term is applied to an alloy for metallic foils used by the Chinese for lining tea-chests. It is composed of lead 126 parts, tin 17.5, and copper 1.25, besides a trace of zinc.

Alloy for moulds for pressed glass.—An alloy suitable for this purpose is obtained, according to C. H. Knoop, of Dresden, by melting together 100 parts of iron with 10 to 25 parts of nickel.

New methods of preparing alloys.—The alloys consist of heavy metals and the sulphides of the alkali metals or metals of the alkaline earths. Preferably sulphide of strontium is alloyed with copper in order to obtain a pro-

duct of a constant gold-like color. For this purpose zinc is melted together with 8 to 15 per cent. of calcined strontium sulphate and the resulting alloy allowed to cool. To this alloy a varying quantity of copper is added, according to the color and power of resistance required. As much of the zinc as may be desired can be expelled by subsequent cupellation.

E. Plazet of Paris has patented the following process.* Chromium is added to metals or alloys, such as copper, nickel, aluminium, gold, silver, zinc, lead, platinum, tin, manganese, tungsten, etc. The chromium must be pure (prepared by electrolysis) and may be coated with copper, etc., to prevent oxidation. It makes the alloy harder and increases electrical resistance. To facilitate the admixture of the chromium certain substances used as oxides, borates, or fluorides of zinc or manganese may be added. Alloys thus prepared are suitable for many purposes, and as non-magnetic metal for bells, watches, etc.

Alloys of indium and gallium.—L. de Boisbaudran, the discoverer of gallium, has experimented with alloys of indium and gallium. They are distinguished by not having a fixed melting point, but soften gradually, like fats. In this semi-liquid condition they form a mixture of melted and crystalline metal. L. de Boisbaudran has prepared the following alloys:

1. Indium 227 parts, gallium 69.9 parts. This alloy is white, granular, and can be readily cut with the knife; it begins to melt at 132.8° F., and is viscid at 167° F.

2. Indium 113.5 parts, gallium 69.9. This alloy forsm a white coherent mass, but is still softer than the first alloy. It is hard at 60.8° F., semi-liquid at 113° F., and liquid at from 140° to 176° F.

3. Indium 113.5 parts, gallium 139.8. White; soft. It hardens at 60.8° F., is butyraceous at 64.4° F.; liquid from 140° to 176° F.

*English patent 202. 1896.

4. Indium 113.5 parts, gallium 279.6. This alloy is white, commences to melt at 62° F., is semi-liquid at 95° F., and liquid at 122° F.

Steel composition.—Steel shavings 60 parts, copper 22.5, mercury 20, tin 15, lead 7.5, and zinc 15, are gradually introduced and dissolved in 860 parts of nitric acid. The resulting reddish-brown paste is dried, melted together with twenty times its weight of zinc, and the mass cast in ingots. After cooling, the alloy is remelted with a corresponding addition of tin, according to whether it is to be softer or harder.

Alloys for drills, chisels, etc.—These alloys have the advantage over hardened steel in that tools made from them do not require tempering or dressing when in use. Castings are simply made and an edge ground on with an emery wheel.

	I. For drills, chisels, etc.	II. For cutters, etc.
Cast iron	17.25	17.25
Chromium	1.50	2.00
Ferro-manganese	3.00	4.50
Tungsten	5.25	7.50
Aluminium	1.25	2.00
Nickel	0.50	0.75
Copper	0.75	1.00
Wrought iron	70.50	65.00

The alloys are prepared by first melting in a graphite crucible the cast iron and tungsten, then covering the melted mass with charcoal and borax and adding the ferro-manganese and chromium. The alloy thus obtained, together with the wrought iron, is again liquefied in a clay crucible and the copper, nickel and aluminium are added. The contents of the crucible are covered with charcoal, and the alloy is finally cast in sand moulds.

Alloys of iron with chromium, tungsten, molybdenum,

etc. For the preparation of such alloys the Electro-Metallurgical Co. of London has patented the following process:* Previous to adding the chromium, etc., to the melted iron or steel its content of oxygen is entirely withdrawn by aluminium. The effect of this is that as all the chromium, etc. added alloys with the iron, and only a very minute portion of it is used for the deoxidation of the iron, the intended percentages of the additions can be accurately maintained.

Alloys of copper and iron are prepared according to a method patented by A. F. V. M. Baron, of Paris,† by heating the copper to a cherry or very bright red heat, then adding the required quantity of a mixture of rosin and an oxalate or another similar organic salt which, when decomposed by the heat, evolves carbonic oxide, carbonic dioxide and water, and finally adding the required quantity of iron.

Malleable ferro-cobalt and ferro-nickel. For the direct gaining of malleable ferro-cobalt or ferro-nickel, the "Fonderie de nickel et métaux blancs" of Paris claims to utilize either the ores themselves, or to prepare first an especially suitable initial product for the final result by melting together corresponding quantities of nickel or cobalt and chromium ores. In melting together the ores the degree of heat at which the liquation of the iron would take place must, however, not be attained. This product of melting, or the raw materials themselves, are melted together in a suitable crucible with potassium ferrocyanide and peroxide of manganese. In running off, a small quantity of aluminium is added. According to the condition desired for the final product, and according to the original content of iron of the ores, a larger or smaller quantity of cast-iron or wrought-iron can be added from the start, whereby a more or less soft and malleable product is obtained. If, for instance, an alloy of 70 per cent. of nickel and 30 per cent. of

* German patent, 90,746. † U. S. patent, 577,182, 1897.

iron, with a very small content of sulphur, be used, 71.9 parts of fused nickel, 12 of peroxide of manganese, 16 of potassium ferrocyanide, and 0.1 of aluminium are taken for the mass to be melted together. If, however, nickel ore containing only about 25 per cent. of pure nickel, with 64 per cent. of iron and 11 per cent. of other admixtures, be used, the melting material is best composed of about 82 parts of fused nickel, 8 of peroxide of manganese, and 10 of potassium ferrocyanide. The alloys thus obtained are claimed to excel in perfect malleability, and completely to retain this property when remelted, so that, on the one hand, malleable ingots are at once produced, and, on the other, all waste and defective castings can be again utilized.

Bronze resisting acids.—Débié gives the following receipt: Copper 15 parts, zinc 2.34, lead 1.82, antimony 1. This alloy melted in a crucible can be worked in the ordinary manner, and is claimed to answer as substitute for lead for lining vessels used in the manufacture of sulphuric acid, etc.

Zinc-iron, being very brittle, is used very seldom as an alloy, but on account of its brilliant light promises to become of considerable value for pyrotechnics. Theoretically it is also interesting as an alloy of a very volatile with a non-volatile metal, and, further, it offers the readiest means of obtaining zinc in a finely divided state for purposes where the presence of iron is not objectionable. The best method of preparing the alloy is as follows: Heat 1 to 2 pounds of zinc in a clay crucible to the melting point, then throw 3 to 3.5 ounces of anhydrous sodium ferrous chloride upon the surface of the melted zinc and immediately cover the crucible. A very vigorous reaction takes place during the formation of the alloy mixed with zinc chloride ($Zn + FeCl_2 + Fe$). The excess of the zinc alloys with the reduced iron and forms the exceedingly brittle zinc-iron which can be readily pulverized.

An alloy which expands on cooling is prepared from lead

9 parts, antimony 2, and bismuth 2. It is very suitable for filling up small holes and defective places in cast-iron.

Spence's metal.—This compound is an English invention, and is named after the inventor. Strictly speaking, it is not a metal, but a compound obtained by dissolving metallic sulphides in melted sulphur, which is found to be capable of receiving into solution nearly all the sulphides of the metals. For most purposes Mr. Spence employs in the production of his "metal" the sulphides of iron, lead and zinc, in varying proportions, according to the quality of the product desired, which will depend on the uses for which it is designed. On cooling the mixture solidifies, forming a homogenous, tenacious mass, having ordinarily a specific gravity of 3.37 to 3.7. It is said to be exceedingly useful in the laboratory for making the air-tight connections between glass tubes by means of rubber and a water or mercury jacket where rigidity is no advantage. The fusing point is so low that it may be run into the outer tube on to the rubber, which it grips, on cooling, like a vise and makes it perfectly tight. It melts at 320° F., expands on cooling, is claimed to be capable of resisting well the disintegrating action of the atmosphere, is attacked by but few acids and by them but slowly, or by alkalies; is insoluble in water and may receive a high polish. It makes clean, full castings, taking very perfect impressions; it is cheap and easily worked. It has been used as a solder for gas-pipes and as a joint material in place of lead.

Lutecine, or Paris metal.—Copper 800 parts, nickel 160, tin 20, cobalt 10, iron 5, and zinc 5.

Alloys for small patterns in foundries.

I. Tin 7.5 parts, lead 2.5.

II. Zinc 75 parts, tin 25.

III. Tin 30 parts, lead 70.

The last of these alloys is for patterns which will not be in frequent use and which may be mended, bent, etc. The first gives harder and stiffer patterns; the second is harder

than tin and more tenacious than zinc, while at the same time it preserves a certain ductility.

Alloys for calico-printing rollers.—Hauvel considers a semi-hard bronze of the following composition the best material for the rollers: Copper 86 parts, tin 14, zinc 2.

Rendel, on the other hand, found an English roller material composed of: Copper 5.6 parts, zinc 78.3, tin 15.8. Though this compound gives a hard, fine-grained alloy, it is likely to be very readily attacked by the colors used in printing.

According to analysis by J. Dépierre and P. Spiral, the composition of the scrapers (sometimes called doctors or ductors) intended to remove the surplus of colors from the rollers is as follows:

	Copper.	Zinc.	Tin.
Yellow French scrapers	78.75	12.50	8.75
Yellow English scrapers	80.50	10.50	8.00
Yellow German scrapers	85.80	9.80	4.90

According to the researches of the above-named scientists, three groups are to be distinguished: 1. Copper with 95 to 100 per cent. of copper; 2. Brass with about 60 per cent. of copper and 40 per cent. of zinc; and 3. Alloys. In the annexed table I, the physical properties of the examined pieces are given, whereby it has, however, to be remarked that in rollers for printing calico, where the hardness of the metal is of considerable importance, the chemical composition alone does not express the characteristics of the metal, they depending also on the manner of hardening and tempering.

Table II, shows the chemical composition of the samples.

Besides red copper the alloys containing 25 to 30 per cent. of zinc and 75 to 70 per cent. of copper are essentially suitable for rollers. Even as small a content of lead as 0.5 per cent. exerts an injurious influence, and the samples containing lead showed blow-holes. The presence of phosphorus could not be detected in any of the samples, but

Messrs. Dépierre and Spiral are of the opinion that rolls of copper, containing 1 to 2 per cent. of phosphorus, would yield excellent results as regards resistance against chemical influences, as well as hardness, fineness of grain, homogeneousness and durability. An addition of one per cent. of phosphorus might also be recommended for varieties of brass containing 30 to 35 per cent. of zinc.

Table I.

Sample.	Color.	Class.	Density.	Grain.	Hardness.	Remarks.
1	red	1	8.82	coarse	hard	——
2	"	1	8.83	fine	"	——
3	"	1	8.82	coarse	very soft	——
4	"	1	8.83	very fine	medium	——
5	yellow	3	8.40	coarse	hard	blow-holes.
6	"	2	8.25	very fine, homogeneous	"	——
7	"	3	8.58	fine, not homogeneous	very brittle	——
8	red	1	8.88	very fine	hard	burnt.
9	"	1	8.80	coarse	soft	suitable for printing.
10	yellow	2	8.15	very fine [ous	hard	very unequal.
11	"	3	8.45	coarse, homogene-	"	——
12	"	3	8.50	fine, not very homogeneous	very brittle	many blow-holes (1835).
13	red	1	—	——	—	very good.
14	"	1	8.90	fine	hard	bad.
15	yellow	3	8.35	"	"	very good.
16	"	3	8.20	"	"	blow-holes.
17	"	2	8.10	fine, homogeneous	"	very bad.
18	red	1	8.90	fine	"	good.
19	—	—	—	——	—	——
20	yellow	2	8.20	coarse, not very homogeneous	soft	——
21	"	2	8.15	fine, homogeneous	hard	——
22	"	2	8.22	middling	soft	——
23	red	1	8.85	fine	hard	——
24	yellow	2	—	——	—	——
25	gray-yellow	3	—	——	—	attacked by colors.

Table II.

	No. of the samples.	Copper.	Tin.	Lead.	Zinc.	Remarks.
Copper.	3	99.11	0.05	0.12	0.57	
	4	99 16	0.02	0.12	0.58	some aluminium.
	8	99.13	0.03	0.19	0.45	some aluminium and sulphur.
	9	99.03	0.03	0.12	0.00	" " "
	1	99.93	traces	0.14	0.67	" " "
	2	99.07	"	0.07	—	" " "
	14	99.40	"	0 48	—	
	13	99.84	"	traces	—	
	23	99.52	"	—	—	
Brass.	6	60.33	0.03	0.68	38.68	
	19	61.70	0.08	0.64	37.51	
	20	64.41	0.21	2.00	31.88	
	22	68.60	—	0.39	30.53	
	21	58.25	—	0.43	41.02	
	17	77.68	traces	0.42	21.41	
Alloys.	11	74.51	2.80	2.18	19.85	all contain traces of arsenic and iron.
	12	76.96	2.55	1.88	17.83	
	7	77.63	2.58	1.94	17.10	
	5	74.12	2.37	2.02	20.50	
	15	79.42	4.17	1 23	14.49	
	10	72.15	3.27	1.71	22.10	
	24	70 40	—	0.60	28.0	
	25	15.0	—	—	64.0	

Alloy for compensation balances. For this purpose Berguet uses the following alloy: Silver 2 parts, copper 2 parts, zinc 1 part. The silver is first melted and the zinc, in small pieces, is then thrown in. The metals are stirred together and, to prevent the volatilization of zinc, are left on the fire for as short a time as possible. The mixture is poured out and allowed to get cold. The copper is then melted, the cold alloy of silver and zinc added, and the whole intimately mixed by stirring. The alloy is then poured out, when cold cut into pieces, and the latter are remelted to obtain a perfectly homogeneous alloy, care being had, however, not to leave the alloy over the fire longer than absolutely

necessary. The resulting alloy is hard, elastic, very ductile, and quickly melts in the furnace.

Black bronze. Tin 5 parts, copper 83 parts, lead 10 parts, zinc 2 parts. Castings made of this alloy, when heated in a muffle after finishing, assume a dead black appearance.

Sideraphite. The alloy known under this name resembles silver, and is very ductile and malleable. It is composed of iron 63 parts, nickel 23, tungsten 4, aluminium 5, and copper 5. The iron and tungsten are melted together and then granulated by being thrown into water. The water used for this purpose should contain 1 lb. of slaked lime and 1 lb. of potash for every gallon. The nickel, copper and aluminium are also melted together, and the product thus obtained is also granulated in water containing the same proportion of lime and potash. During melting the metals in the two crucibles must be kept covered with a flux made of 2 parts each of borax and saltpeter. A piece of soda or alkali, weighing about the $\frac{1}{2500}$ part of the whole mass, is to be put in the crucible containing the copper, nickel and aluminium to prevent oxidation of the last-named metal, and to prevent the same action taking place with the copper a small piece of charcoal is added. Previous to the operation of granulation the contents of the two crucibles should be well stirred. The granulated metals are dried, melted in the proportions given above, well shaken, and then run into bars. This alloy is claimed not to be more expensive than ordinary white metal. It will resist the action of sulphuric acid, is not attacked by organic acids, and but slightly so by the inorganic acids.

Violet-colored alloy. An alloy of a beautiful violet color is obtained by melting together equal parts of antimony and copper.

Gold-like alloy. This is a French alloy and in many respects very closely resembles gold, especially as regards color. It can be forged, welded, rolled, and pressed. It possesses the special advantage of its color not being at-

tacked by ammoniacal salts and vapors containing nitric acid. It consists of copper 96 per cent. and antimony 4 per cent. ' The two metals are melted together and to increase the density of the alloy, a small quantity of magnesium and of calcium carbonate is added.

Pyrophorous alloys for illuminating purposes. In the Auer von Welsbach works such metallic alloys have been prepared from rare earths with the addition of other metals, especially iron. An alloy consisting of about 50 per cent. lanthanium, 30 per cent. of other rare earths, such as neodymium, praseodymium, cerium, and 20 per cent. iron, is very suitable for the production of light, and an alloy consisting of 60 per cent. cerium, 10 per cent. other rare earths and 30 per cent. iron is particularly well adapted for the formation of sparks.

Alloy for silvering. This alloy consists of tin 80 parts, lead 18, silver 2; or tin 90 parts, lead 9, silver 1. Melt the tin, and when the bath is lustrous white add the granulated lead and stir the mixture with a pine stick; then add the silver and stir again. Increase the fire for a short time until the surface of the bath assumes a light yellow color, then stir thoroughly and cast the alloy into bars. The operation of silvering is executed as follows:

The article, for instance a knife blade, is dipped in a solution of hydrochloric or sulphuric acid, rinsed in clean water, dried, rubbed with a piece of soft leather or dry sponge, and then exposed in a muffle five minutes to a temperature of 158° to 176° F. The effect of this treatment is to render the surface of the iron or steel porous. With iron not very good and coarsely porous the silvering process is difficult to execute. With steel, however, the process is easy; the article heated to about 140° F. is dipped into the alloy melted in a crucible over a moderate fire. The bath, which must be completely liquid, is stirred with a pine or poplar stick. The surface of the bath should show a fine silver-white color. One or two minutes' dipping suffices for a

knife blade. When taken from the bath the article is dipped into cold water, or, if necessary, hardened and tempered in the usual manner. It is then rubbed dry and polished without heating.

Articles thus treated have the appearance of silver and also possess the sound of silver, and resist oxidation in the air. To protect them from the action of acid liquids they are first dipped in an amalgam bath of 69 parts of mercury, 39 parts of tin, and one part of silver; then, while hot, in melted silver, and electroplated with silver. This method of silvering is claimed to be very durable and not costly.

Robertson alloy for filling teeth.—Gold 1 part, silver 3, tin 2. First melt the gold and silver in a crucible, and at the moment of fusion add the tin. The alloy, when cold, may be finely pulverized. Equal quantities of the powder and mercury are kneaded together in the palm of the hand to form a paste for filling teeth.

American sleigh-bells.—These bells, exceeding in beauty, fine tone, and small specific gravity, are manufactured by fusing together 10 parts of nickel and 60 of copper. When this alloy has become cold, add 10 parts of zinc and two-fifths part of aluminium, fuse the mass and allow it to cool; then remelt it with the addition of $\frac{2}{5}$ part of mercury and 60 parts of melted copper.

Alloy for casting small articles.—Fuse a mixture of 79 per cent. of cast-iron, 19.50 of tin, and 1.50 of lead. This alloy has a beautiful appearance, fills the mould completely, and is therefore well adapted for casting small articles. It is malleable to a certain extent.

Marlie's non-oxidizable alloy.—Iron 10 parts, nickel 35, brass 25, tin 20, zinc 10. Articles prepared from this alloy are heated to a white heat and dipped into a mixture of sulphuric acid 60 parts, nitric acid 10, hydrochloric acid 5, and water 25.

Alloy for sign-plates.—An excellent metal for engraving firm names, etc., upon plates which are to be attached to

machines, etc., is prepared as follows: Mix 100 parts of pure melted copper in succession with 6 parts magnesium, 57 parts sal ammoniac, 18 parts unslaked lime, and 9 parts cream of tartar, all the ingredients to be in a finely pulverized state. Now, while stirring constantly, add 15 parts of zinc or tin in small pieces, and continue stirring until the whole is thoroughly melted and mixed. Allow the alloy to remain quietly on the fire for half an hour longer, remove the scum, and pour out the metal. This alloy has a golden color, a very fine grain, is ductile, and does not readily lose its color.

Victor metal is whiter than German silver, which it can often replace, though less easy to work. It perfectly withstands the effect of salt water and air, and is frequently utilized for marine engines. It is composed of copper 49.94 per cent., zinc 34.27, nickel 15.40, aluminium 0.11, iron 0.28.

Tempered lead.—Lead 98.51 per cent., antimony 0.11, tin 0.08, sodium 1.3. It is manufactured by placing small fragments of sodium in the melted metal. This alloy is not so soft as lead, and can be rolled into thin sheets without tearing. When the percentage of sodium is rather large, tarnishing is prevented by coating the metal with paraffin. Thus formation of soda is prevented, owing to oxidation of the excess of sodium by atmospheric oxygen. For this reason it is valued for the manufacture of shaft bearings, because the soda formed, as the bearings wear away, saponifies the lubricant and produces a soap which acts even better than the oil.

CHAPTER XXI.

SOLDERS AND SOLDERING.

Solders in General.

The so-called solders are alloys in the true sense of the word, but being used for special purposes will have to be separately described. Soldering is the process of uniting the edges or surfaces of metals by means of a more fusible metal which, being melted upon each surface, serves, partly by chemical attraction and partly by cohesive force, to bind them together. There is a great variety of solders known by the names of *hard*, *soft*, *spelter*, *silver*, *white*, *gold*, *copper*, *tin*, *plumbers'*, and many others; they may, however, be broadly distinguished as *hard solders* and *soft solders*. The former fuse only at a red heat, and are therefore only suitable for metals and alloys which will stand that temperature; the soft solders fuse at a comparatively low temperature, and may consequently be used for nearly all metals. Nearly all the principal metals take part in the composition of solder. The metals to be united may be either the same or dissimilar, but the uniting metal must always have an affinity for both, and should agree with them as nearly as possible in hardness and malleability. When this is the case, as when zinc solder is used to unite two pieces of brass or of copper, or one piece of each, or when lead or pewter is united with soft solder, the work may be bent or rolled almost as freely as if it had not been soldered. But when copper or brass is united by soft solder, the joint is very liable to be broken by accidental violence or the blow of a hammer. In all soldering processes the following conditions must be observed: 1. The surfaces to be united must be bright,

smooth, and chemically clean. 2. The contact of air must be excluded during the soldering, because it is apt to oxidize one or other of the surfaces, and thus to prevent the formation of an alloy at the point of union. This latter object is effected by means of fluxes, which will be referred to later on.

The process called *autogenous soldering* takes place by the fusion of the two edges of metals themselves without interposing another metallic alloy as a bond of union. The process is possible with the majority of metals and alloys, even the refractory ones, and though it does not actually belong here, the subject being alloys, it will be briefly described. The union of the metals is accomplished by directing a jet of burning oxyhydrogen gas from a small movable beak upon the two surfaces or edges to be soldered together. Metals thus joined together are much less apt to crack asunder at the line of union by differences of temperature, flexibility, etc., than when the common soldering process is employed. This method of soldering is especially of great advantage in chemical works for joining the edges of sheet lead for sulphuric acid chambers and concentrating pans, because any solder containing tin would soon corrode.

All soldered work should be kept under motionless restraint for a period, as any movements of the parts during the transition of the solder from the fluid to the solid state disturbs its crystallization and the strict unity of the several parts. In hard soldering it is frequently necessary to bind the work together in their respective positions; this is done with soft iron *binding wire*, which for delicate jewelry work is exceedingly fine, and for stronger work is $\frac{1}{20}$ or $\frac{1}{30}$ inch in diameter; it is passed around the work in loops, the ends of which are twisted together with the pliers.

In soft soldering the binding wire is scarcely ever used, as, from the moderate and local application of the heat, the hands may in general be freely used in retaining most of the work in position during the process. Thick work is

handled with pliers or tongs whilst being soft-soldered, and the two surfaces to be united are often treated much like glue joints, if we conceive the wood to be replaced by metal and the glue by solder, they being frequently coated or tinned whilst separated, and then rubbed together to distribute and exclude the greater part of the solder.

Soft Solders.

The soft solders serve chiefly for soldering tin-plate, sheet-zinc, and kitchen utensils of sheet-brass. Their melting points lie between 284° and 464° F. For special purposes, the two previously mentioned alloys of cadmium and bismuth, with as low a melting point as 140° F., would be very suitable, but their costliness prevents their general use.

Pure tin is the simplest of all soft solders, and is frequently used for soldering fine utensils of tin. Absolutely pure tin should, however, only be used, as the presence of foreign metals, especially that of iron, considerably increases the melting point. Tin solder is generally employed in the form of semi-cylindrical bars or very thin prisms. For soldering very delicate work tin-foil of very pure tin is frequently used. The surfaces being thoroughly cleansed, and, if necessary, nicely fitted together with a file, a piece of tin-foil is placed between them. They are then firmly bound together with binding wire and heated in the flame of a lamp or a Bunsen burner, or in the fire, until the tin melts and unites with both surfaces. Joints carefully made may be united in this way so neatly as to be invisible.

The soft solder most frequently used consists of 2 parts of tin and 1 of lead. A cheaper solder is formed by increasing the proportion of lead; 1½ tin to 1 lead is the most fusible solder, unless bismuth is added. The following table gives the composition of some of these solders with their points of fusion :—

No.	Parts.		Melts at degrees F.	No.	Parts.		Melts at degrees F.
	Tin.	Lead.			Tin.	Lead.	
1	1	25	558°	7	1½	1	334°
2	1	10	541	8	2	1	340
3	1	5	511	9	3	1	356
4	1	3	482	10	4	1	365
5	1	2	441	11	5	1	378
6	1	1	370	12	6	1	381

For ordinary plumber's work the solders from 4 to 8 are used with tallow as a flux. For lead and tin pipes No. 8 is used with a mixture of rosin and sweet-oil as a flux. For Britannia metal No. 8 is used with chloride of zinc or rosin as a flux. It can also be used for soldering cast-iron and steel, with common rosin or sal ammoniac as a flux. The same solder can also be used for copper and many of its alloys, such as brass, gun-metal, etc., sal ammoniac, chloride of zinc, or rosin being used as a flux. The solder No. 5 is what is called in England *plumbers' sealed solder*, which is assayed and stamped by an officer of the "Plumbers' Company."

The preparation of soft solder is very simple. The tin is first melted, a porcelain or stoneware vessel being best adapted for the purpose, as with the use of iron vessels there is danger of the absorption of iron by the solder. The tin being completely melted, the lead is added, and the two metals are thoroughly combined by stirring. The finished alloy is then poured into suitable moulds.

Many manufacturers simply pour the finished solder in a fine stream upon a stone slab, and subsequently break the sheet thus obtained into small pieces. It is, however, recommended to cast the solder in moulds, as it is more handy for working in this shape, and besides its composition can be better controlled. The most suitable shape is that of thin bars about 7¾ by 1½ inches and ⅛ to ¼ inch thick.

Experts judge the quality of a solder by the appearance of the surface of the cast pieces, and attach special value to its being radiated-crystalline, which is technically called the "*flower*," and should have a stronger luster than the dull ground of a dead silver color. If, as it sometimes happens, the solder shows a uniform gray-white color, it contains too little tin, and it is best to remelt it with an addition of a small quantity of tin.

Bismuth solder is composed of bismuth 1 part, tin 1, and lead 1. It melts at 284° F. As will be seen from the composition, it is more expensive than ordinary solder on account of the content of bismuth. It is, however, well adapted for certain purposes, as it is very thinly-fluid and considerably harder than ordinary solder.

As previously mentioned every readily fusible metallic composition can be used for soldering, and consequently the fusible alloys of cadmium and of bismuth might be classed with the soft solders. They are, however, only used in exceptional cases on account of their costliness.

Hard Solders.

Under this name many different alloys are used, their composition depending principally on that of the metals or alloys to be soldered. Though hard solders are found in commerce, many large manufacturers prefer to make their own solders in order to have them entirely suitable for the purpose they are intended for. According to the metals or alloys for which they are to be used, hard solders may be divided into brass-solder for soldering brass, copper, etc., argentan-solder for German silver, gold and silver solders for gold and silver, etc., and this division will be retained here.

Brass solder is the most fusible of all hard solders and is prepared according to various proportions. It is generally made by melting a good quality of brass together with a determined quality of pure zinc, or sometimes adding some

tin to the mixture. Some solders are composed of brass 8 parts, zinc 1. A somewhat more refractory composition consists of brass 6 parts, zinc 1, and tin 1. And a still more refractory one of brass 6 parts, zinc 1, tin 1, copper 1. The latter solder is the so-called hard brass-solder and is used for soldering iron and copper. In speaking of the respective alloys attention was drawn to the fact that with an increase in the content of tin the color of the brass passes from golden-yellow more and more into gray, and that the ductility decreases at a corresponding rate. Varieties of brass very rich in tin are no longer ductile, but possess a considerable degree of brittleness. By adding tin to such compositions, their hardness and brittleness are still further increased, and mixtures are thus obtained, which, according to their peculiar color, are designated as *yellow*, *half-yellow* or *half-white*, and *white* solder.

Regarding the quantity of metals to be added to the brass, it has to be taken into consideration that solders containing much tin, though quite thinly-fluid, acquire such a degree of brittleness as to break in most cases on bending at the soldered place.

In making solders great care should be taken to secure uniformity of composition; they are often found in commerce in a granulated form or cast in ingots. The most suitable mode of their preparation is as follows: Perfectly homogeneous sheet-brass is used, it being preferable to cast brass, as by rolling it has acquired greater homogeneousness. To prepare the brass for the manufacture of solders directly by melting together copper and zinc, is not advisable, as the unavoidable loss of zinc during the operation can never be exactly determined. By using finished brass it can, however, be readily melted down and compounded, if necessary, with zinc, without any sensible volatilization of the latter.

The brass is first melted in a crucible at as strong a heat as possible, and when thoroughly fused the entire quantity

of zinc to be used in the manufacture of the solder, and which has previously been highly heated, is added. The contents of the crucible are then vigorously stirred and after a few minutes poured out. The granulation of the solder is effected by pouring the melted metal from the crucible or ladle through a wet broom or from a considerable height into cold water. The size of the grains thus obtained varies within wide limits, and in order to obtain a uniform product the grains have to be passed through different-sized sieves and all excessively large pieces remelted.

According to another method, the melted metal is poured into a shallow vessel filled with cold water in which lies a large cannon ball so as partially to project from the fluid. The metal falling in a fine stream upon the cannon ball flies into small pieces of nearly uniform size, which fall into the water, where they quickly harden.

The finest and most beautiful product is, however, obtained in the following manner: At some distance above the level of the water serving for the collection of the grains, a horizontal pipe is arranged which is connected either with a powerful forcing pump or a water reservoir situated at a high level. Before pouring out the melted metal the cock on the pipe is opened so that the jet of water issuing from the pipe is thrown in a horizontal direction over the vessel containing the water; upon this jet of water the stream of melted metal is poured. The greater the force with which the water is hurled from the pipe the greater also the force with which the stream of melted metal is divided, and by this means it is possible, within certain limits, to obtain grains of a determined size. As will be seen from the above description the scattering of the stream of melted metal is based on the same principle as that employed in diffusing fragrant liquids in the air.

Casting being finished, the grains of solder deposited on the bottom of the vessel are collected and quickly dried to

prevent them from becoming covered with a layer of oxide, which would exert a disturbing influence in soldering.

The following table shows the composition of various kinds of solder which have stood a practical test for various purposes:—

	Copper.	Zinc.	Tin.	Lead.
	per cent.	per cent.	per cent.	per cent.
Very refractory	57.94	42.06	—	—
" "	58.33	41.67	—	—
Refractory	50.00	50.00	—	—
Readily fusible	33.34	66.66	—	—
Half-white, readily fusible	44.00	46.90	3.30	1.20
White	57.44	27.98	14.58	—
Malleable solder	72.00	18.00	4.00	—
Hard solder according to Volk	53.30	46.70	—	—

Since these solders, as previously mentioned, are generally prepared by melting together brass and zinc, we give in the following table the proportions of brass (in sheet) and zinc required for the purpose.

	Parts.		
	Brass.	Zinc.	Tin.
Very refractory	85.42	12.58	—
" "	7.00	1.00	—
Refractory	3.00	1.00	—
"	4.00	1.00	—
Readily fusible	5.00	2.00	—
" "	5.00	4.00	—
Half-white	12.00	5.00	1.00
"	44.00	20.00	2.00
White	40.00	2.00	8.00
"	22.00	2.00	4.00
"	18.00	12.00	30.00
Very ductile	78.25	17.25	—
For girdlers	81.12	18.88	—

Prechtl's brass-solders.

	Parts.			
	Copper.	Zinc.	Tin.	Lead.
Yellow, refractory	53.30	43.10	1.30	0.30
Half-white, readily fusible	44.00	49.90	3.30	1.20
White	57.44	27.98	14.58	

Brass-solders according to Karmarsh.

	Composition of the solder.			
	Brass.	Zinc.	Copper.	Zinc.
Yellow, very refractory	7	1 =	58.33	41.67
" refractory	3 to 4	1 =	50.00	50.00
" readily fusible	5	2 to 5 =	33.34	66.66
Half-white	12	4 to 7 and 1 tin		
"	22	10 " 1 "		
White	20	1 " 4 "		
"	11	1 " 2 "		
"	6	4 " 10 "		

Improved hard solder for brass.

	Per cent.		
	Copper.	Zinc.	Silver.
1. Fuses well	50	46	4
2. Fuses readily	43	48	9
3. Fuses rapidly	36	52	12

These solders are said to be thoroughly reliable and though they are somewhat more expensive on account of their content of silver, time and fuel are saved with their use. For general use in workshops No. 2 can be recommended, it being suitable for brass of every kind and shape. No. 1 is intended for the first soldering, and No. 3 as a substitute for all hard solders fusing quickly.

Brass-solders containing lead are very rarely used at the present time, those containing besides copper, zinc, and perhaps a small quantity of tin, being generally preferred.

Argentan-solder.—The metallic mixture to which this term is applied, not only serves for soldering articles of argentan or German silver, but, on account of its refractory

character and considerable toughness, is generally used for soldering articles where the joints are to be especially solid. It is very frequently employed for soldering fine articles of steel and iron.

As regards its centesimal composition, argentan-solder is a variety of German silver especially rich in zinc, which must show considerable brittleness, so that it can be mechanically converted into a fine powder. The proportions according to which the solder is composed vary, and depend chiefly on the composition of the articles of German silver to be soldered with it. Manufacturers of German silver articles especially rich in nickel, and consequently more difficult to fuse, use, as a rule, a somewhat more refractory solder than those manufacturing alloys which contain but little nickel, and which are consequently more fusible.

As argentan-solder is not only employed for soldering German silver, but also for articles of steel, efforts have been made to prepare compositions answering all demands, of which the following have stood a practical test:—

a. Readily fusible argentan-solder.—Copper 35 parts, zinc 57, nickel 8.

b. Less fusible argentan-solder (especially adapted for iron and steel).—Copper 38 parts, zinc 50, nickel 12. The alloys are melted in the same manner as German silver and cast in thin plates, which, while still hot, are broken into pieces and converted into as fine a powder as possible in an iron mortar previously heated. If the alloy is readily converted into powder, it contains too much zinc, or, if with difficulty, too little zinc. But in either case it does not possess the properties of argentan-solder of the proper proportions, and nothing is left but to remelt it. Hence it is recommended first to ascertain by small samples whether the alloy has the correct composition. For this purpose a small quantity of the melted metal is taken from the crucible by means of a ladle and poured upon a cold stone, and

then tested as to its behavior in the mortar. If it can be readily pulverized, it indicates an excess of zinc.

This excess of zinc can be removed by keeping the alloy in flux for some time with the crucible uncovered, whereby a considerable quantity of zinc volatilizes, and, after continuing the heating for some time, an alloy showing the required content of zinc is obtained. This method is, however, expensive, as it consumes time and a considerable quantity of fuel. It is, therefore, more suitable to throw small pieces of strongly heated German silver into the melted alloy, and effect an intimate mixture of the metals by stirring with a wooden rod.

If a sample of the alloy cannot be pulverized or broken into pieces by vigorous blows with a hammer, it is a sure proof that zinc is wanting. This defect can be more readily corrected than the preceding one, it being only necessary to throw a small quantity of zinc into the crucible and distribute it as uniformly as possible in the melted mass. After repeating the addition of zinc and testing once, or at the utmost twice, a solder answering all requirements will be obtained.

Argentan-solder has a pure, white color and strong luster. It melts at quite a high temperature and for this reason is well adapted for soldering, for instance, lamps used for the production of high temperatures (so-called Berzelius lamps) which were formerly much used in chemical laboratories, but which at present are generally replaced by gas.

Solders Containing Precious Metals.

Solders containing precious metals—gold and silver—are chiefly used in the manufacture of gold and silver wares, but are also employed for soldering articles of cast-iron, copper, bronze, etc., and by manufacturers of fine mechanical works. Generally these solders consist of an alloy of silver and copper, or silver and brass, for silver-solder;

sometimes a small quantity of tin is added, which lowers the melting-point and gives a soft silver-solder. The composition of silver solders varies according to the purpose for which they are to be used. In the following the compounds employed in the preparation of the solders most frequently used are given.

Ordinary hard-silver-solder.—Copper 1 part, silver 4. This alloy is quite tenacious and very ductile. It is preferably used for soldering articles to be worked under the hammer or to be stamped.

Brass silver-solder.—The alloy known under this name shows also considerable hardness and ductility, and has a somewhat lighter color than the preceding. It is prepared by melting together a fine quality of brass with silver, and is consequently an alloy of silver, copper and zinc. It is composed of sheet-brass 1 part and silver 1.

Soft silver-solder.—The solders given above have a comparatively high melting point. To facilitate the working of smaller articles, solders with lower melting points are used. This is attained by the addition of a small quantity of tin, which must, however, be very pure. An excellent soft silver-solder is composed of sheet-brass 32 parts, silver 32, tin 2.

Hard silver-solders: a. Very hard.—Silver 40 parts, copper 10.

b. Hard.—Silver 40 parts, copper 2, brass 18.

c. Middling hard.—Silver 40 parts, copper 10, brass 40, tin 10.

Soft silver-solders: a. For after-soldering, i. e., for soldering articles that have parts already soldered, silver 20 parts, brass 10.

b. Quick running and brittle.—Silver 25 parts, brass 30, zinc 10.

The last composition is frequently used for soldering silver-alloys with a very small content of silver. In consequence of the great brittleness of such solder, the soldered places readily spring open.

Silver solder for jewelry.—Silver 63.3 parts by weight, copper 3.4, brass 33.3.

French silver solder.—This solder is used for soldering silver wares of the standard 950. Silver 66.6 parts by weight, copper 23.3, zinc 10.

In making this solder it is recommended to previously alloy the zinc with twice its weight of copper, when the following proportions are used: Silver 66.8 parts by weight, brass 30, copper 3.3.

Gee* recommends the following solders for special work:

	oz.	dwt.	gr.
I. Fine silver	1	0	0
Shot copper	0	5	0
	1	5	0

	oz.	dwt.	gr.
II. Fine silver	1	0	0
Shot copper	0	10	0
	1	10	0

	oz.	dwt.	gr.
III. Fine silver	0	16	0
Shot copper	0	0	12
Composition	0	3	12
	1	0	0

	oz.	dwt.	gr.
IV. Fine silver	1	0	0
Composition	0	10	0
Pure tin	0	2	0
	1	12	0

	oz.	dwt.	gr.
V. Fine silver	1	0	0
Shot copper	0	12	0
Pure spelter	0	3	0
	1	15	0

	oz.	dwt.	gr.
VI. Fine silver	1	0	0
Shot copper	0	3	0
Arsenic	0	2	0
	1	5	0

	oz.	dwt.	gr.
VII. Fine silver	1	0	0
Composition	0	6	0
Arsenic	0	1	0
	1	7	0

	oz.	dwt.	gr.
VIII. Fine silver	1	0	0
Composition	0	5	0
Tin	0	5	0
	1	10	0

	oz.	dwt.	gr.
IX. Fine silver	1	0	0
Tin	0	10	0
Arsenic	0	5	0
	1	15	0

	oz.	dwt.	gr.
X. Fine silver	1	0	0
Composition	0	15	0
Arsenic	0	1	6
	1	16	6

*Gee Silversmith's Handbook.

The composition mentioned in the above formulas consists of a mixture of copper and zinc in the proportions of 2 parts of copper to one part of zinc. It is preferable to employ this composition instead of brass, as the operator then knows of what the solder is composed, and if it should turn out bad he will partly know the cause, and be able to apply a remedy.

Nos. I. and II. are recommended for work to be enameled. No. III. easy solder for filigree work. No. IV. easy solder for chains. No. V. common easy solder. No. VII. easy silver solder. Nos. IX and X. common easy solders.

Silver-solder for cast-iron.—Silver 20 parts, copper 30, zinc 10.

Silver solder for steel.—Silver 30 parts, copper 10.

Flux for hard-soldering used in Vienna.—This substance known as *streu-borax* (sprinkle-borax) is composed of calcined borax 87½ parts by weight, carbonate of soda 7½, common salt 5. The ingredients are gently heated to expel the water of crystallization, and the whole is well pounded for use.

For soldering articles of silver the alloy itself of which they are manufactured is in many cases used. But the manipulation is somewhat troublesome on account of the difficulty of keeping the places to be soldered clean, and the pieces must be very nicely fitted together. The solder, in this case, is used in the form of fine shavings and is melted by means of a keen flame. For small articles the flame of a blow-pipe suffices as a rule, but for larger articles it is best to use a special small blowing apparatus, by means of which the solder can be applied very uniformly. It offers the further advantage of leaving both hands free, which is of importance for turning the vessel in front of the flame and for the application of the solder.

Gold-solders.—In color and fusibility the solders used for articles of gold should approach as nearly as possible the

alloys of which the article are made; the smaller the content of gold in the alloy to be soldered, the more fusible the alloy used for soldering must be. Gold-solders consist in most cases of alloys containing, besides gold, copper and silver. By adding, as is sometimes done, small quantities of zinc, solders with a comparatively low melting point are obtained, the use of which has, however, the disadvantage of the soldered places frequently acquiring a black color during the subsequent coloring of the articles.

Manufacturers use for articles of gold of various fineness solders which must correspond in regard to color and fusibility with the alloy to be soldered. The following table gives the composition of some gold-solders in general use:

	Parts.			
	Gold.	Silver.	Copper.	Zinc.
Hard solder for fineness 750	9.0	2.0	1.0	—
Soft " " " 750	12.0	7.0	3.0	—
Solder " " " 583	3.0	2.0	1.0	—
" " " " 583	2.0	0.5	0.5	—
" for less fineness than 583	1.0	2.0	1.0	—
" " " " 583	1.0	2.0	—	—
" " " " 583	1.0	—	2.0	—
" readily fusible	11.94	54.74	28.17	5.01
" " " for yellow gold	10.0	5.0	—	1.0

Solder for enameled work.—Articles which are being finished and are to be decorated with enamel cannot be soldered with every kind of gold solder, since many enamels require so high a degree of heat for fusion as to endanger the durability of the soldered joints. Hence solders with a high melting-point have to be used. The following compositions will be found to answer all requirements:—

a. Refractory solder.—Gold 74 parts, silver 18.

b. More readily fusible solder.—Gold (750 fineness) 32 parts, silver 9, copper 3.

Fine gold solder.—For soldering platinum vessels to be used in laboratories chemically pure gold was formerly used, as alloys of gold and silver are attacked by sulphuric acid, etc., at a boiling heat and even below that temperature. Soldering with fine gold is, however, very difficult, as gold requires a very high temperature to become fluid, and even then runs so thick as to require special skill for the production of a perfect joint. In modern times soldering with gold has been almost entirely abandoned, the pieces of platinum being now directly united with the assistance of the flame of oxyhydrogen gas.

Aluminium gold-solder.—This solder is frequently used by dentists for joining together the separate metallic portions of sets of artificial teeth. Besides aluminium it generally contains gold and silver, though in the place of the latter platinum and copper are now frequently used. In the following we give two receipts for preparing aluminium gold-solder:

I. Gold 3 parts, platinum 0.1, silver 2, aluminium 10.

II. Gold 5 parts, silver 1, copper 1, aluminium 20.

Alloys containing precious metals must, on account of their costliness, be brought into such shape that as little as possible be wasted in using them. In most cases they are cast into thin rods and rolled between steel rolls into thin sheet, which is cut with the shears or pressed into thin strips, the so-called "pallions," or filed into dust, which is no doubt the best method of using them.

Treatment of the various solders in soldering and soldering fluids, etc.

Solders adhere only to bright and clean metal, and the surfaces of the plates to be soldered must consequently be subjected to a special treatment in order to remove any oxide, grease, etc.

Many substances are in practice used for this purpose, the most important of which will be briefly discussed

in the following: According to their behavior the chemical preparations used in soldering can be divided into several groups, namely, in those which produce a bright surface of the metals by dissolving the layer of oxide upon them.

Dilute mineral acids are generally used for pickling the places to be soldered, hydrochloric (muriatic) acid being chiefly employed for the purpose. By touching the place where the solder is to be applied with a brush dipped in dilute hydrochloric acid, the oxide is at once dissolved and the melted solder spreads rapidly over the surface. Hydrochloric acid is used upon zinc as well as upon tin. The combination formed by the solution of zinc in hydrochloric acid is, however, very volatile in the heat imparted to the metal by the soldering iron, and a considerable quantity of vapors injurious to the health and also to the metal of the soldering iron are evolved. It is, therefore, recommended to provide the workshop, where much of such soldering is done, with thorough ventilation.

Instead of dilute hydrochloric acid, the so-called soldering fluid is used in many places. It is prepared by dividing a certain quantity of hydrochloric acid into two equal parts, compounding one of these parts with pieces of zinc and leaving it in contact with an excess of zinc until the development of gas has ceased. The other portion of hydrochloric acid is compounded with carbonate of ammonia until no more effervescence due to the escape of carbonic acid takes place. The two liquids are then combined. In place of the saturated solution of carbonate of ammonia a solution of sal ammoniac in water can be used, equal volumes of the zinc solution and sal ammoniac being in this case taken for the preparation of the soldering fluid.

For brass articles ammonia alone is frequently used, which acts by reducing the layer of oxide upon the surface of the metals. As fluxes for coarser work turpentine, colophony, and a mixture of sal ammoniac and olive oil are also used.

The composition known under the name of "soldering fat" may be prepared by introducing powdered colophony in melted and strongly heated tallow and adding sal ammoniac. The mass is stirred until homogeneous and then allowed to solidify.

For hard soldering, substances are used which dissolve the layer of oxide, and form with it a glass-like combination which is melted by the heat and forced out by pressing the soldered pieces together. The best-known agent of this kind is borax, which readily dissolves the oxides in consequence of the excess of boric acid it contains. For higher degress of temperature, readily fusible glass finely pulverized also does good service, the fused glass dissolving the oxides. A solution of water-glass also answers the purpose, and is frequently used in hard soldering.

Hard-soldering fluid.—The composition known under this name consists of a solution of phosphoric acid in alcohol. It is prepared by dissolving phosphorus in nitric acid, evaporating the solution to expel any excess of nitric acid and mixing the syrupy mass with an equal quantity of strong alcohol. The phosphoric acid dissolves the layer of oxide, the combination formed melting under the soldering iron, and is displaced by the melted solder which now comes in contact with the bright metallic surface. The hard-soldering fluid can be advantageously used in soldering copper, as well as brass, bronze and argentan. The phosphate of ammonia or of soda is also used in soldering copper.

Still more suitable as a flux in hard soldering is the use of quartz-sand and some decomposed soda. Quartz-sand consists of silicic acid and soda or sodium carbonate. Both these substances on coming together in a strong heat combine to sodium silicate, which, if silicic acid be present in excess, dissolves the oxides. For very high temperatures, as for instance in welding iron, the use of pure quartz-sand by itself suffices. By strewing the sand upon the red-hot

iron, placing the other piece of iron also red hot upon it, and uniting both by vigorous blows of the hammer, the combination of the silicic acid with the ferric oxide formed upon the surfaces of the pieces of the metal is pressed out in a fluid form, and the two surfaces of iron having become bright will unite.

In soldering copper and brass, or similar metals, with soft solder, many workmen use the soldering iron exclusively, whilst in many cases a better joint may be made by carefully filing the places to be soldered, so that they fit accurately one upon the other, applying soldering fluid to them, and laying a piece of thin tin-foil between them. The parts are then bound together with wire and held over the lamp until the tin-foil is melted. Solders 19 and 21 in the annexed table may be recommended for this purpose. The fusing points given in the table may be of advantage to the workman in case the same piece of work requires several soldering joints. If, for instance, a joint has been soldered with tin-solder No. 5, an adjoining joint may, without hesitation, be soldered with solder No. 16, the melting points of these two solders being far apart.

soldered, if previously the lower part *A* of the shirt button was fastened between the screws (see Fig. 43).

In Fig. 43 the pan is shown in cross section, to indicate how it is to be used in case a ring with jewel is to be soldered. This is to be fastened as deeply as possible between the screws, and the pan is then filled to a proper height with sand. Above is placed a layer, *O*, of small pieces of coal or asbestos, and soldering may then be commenced without danger to the jewel.

Fig. 43.

CHAPTER XXII.

DETERMINATION OF THE CONSTITUENTS OF METALLIC ALLOYS, OF THE IMPURITIES OF THE TECHNICALLY MOST IMPORTANT METALS, ETC.

SINCE most metals dissolve in nitric acid, pour over the sample in a glass flask chemically pure nitric acid and assist solution by careful heating over a spirit flame.

1. Gold and platinum dissolve only in aqua-regia; tin and antimony are only oxidized by nitric acid. Hence if an undissolved residue of the sample remains, it indicates *gold*, *platinum* or *antimony* (or carbon with cast-iron). Filter the residue, which may be termed *A*, from the solution and treat it further as given under 15.

2. Dilute a sample of the filtrate (or, if filtration be not necessary, a sample of the solution) in a test-glass with distilled water. If turbidity or a white precipitate appears it indicates *bismuth*, which has been precipitated as basic salt from the solution by water. The non-appearance of this reaction, however, is not conclusive proof of the absence of bismuth, since an excess of nitric acid prevents the precipitation of basic bismuth nitrate. To be certain, first evaporate the sample to drive off the acid and then dilute with water.

3. Another sample of the solution is mixed with dilute sulphuric acid. If a white, granular precipitate is formed, the sample of metal contains *lead*, because only sulphates of lead are insoluble in acids.

4. If, on mixing a portion of the original solution, or in case the test for lead was successful, a portion of the filtrate free from lead, with pure hydrochloric acid, a white caseous

precipitate is formed if the metallic sample contains *silver* or *mercury*. In case test No. 3 has not been previously executed, a precipitate of chloride of lead may take place if *lead* is present. For the further treatment of this precipitate, which may be termed *B*, see under 14.

5. Add to a small sample of the solution in nitric acid a few drops of caustic ammonia. If the solution acquires a fine blue color, the sample of metal contains *copper*.

6. To test for *mercury*, evaporate a few drops of the solution in nitric acid to expel the acid, and dilute with water. If a copper wire placed in the aqueous solution turns gray and becomes white with a metallic luster on rubbing with the finger, the presence of mercury is shown.

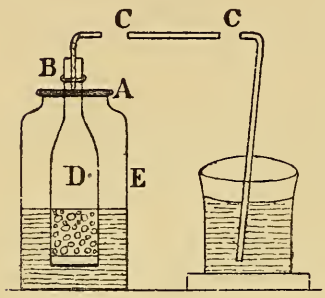
7. Next conduct into a somewhat larger sample of the solution sulphuretted hydrogen and compound it with water containing sulphuretted hydrogen. All metals mentioned in 1 to 6 are precipitated as metallic sulphides. Hence, a precipitate, which may be termed *C*, will generally be obtained. This precipitate is filtered off, thoroughly washed with water containing sulphuretted hydrogen, and further tested for cadmium as given under 16. Since sulphuretted hydrogen is frequently used, it being a reagent of great value to the chemist, a simple and cheap apparatus, so that a supply may at any time be had, may be made as follows: Cut off the bottom of a long glass-bottle* of small diameter, *D*, say about two inches, and fit it into a fruit jar *E*, as in Fig. 44.

The top *A* should be fitted loosely, so that it may be removed to let air pass through. The cork at *B* must be air-tight. Fit a small tube into the cork after bending it in a spirit-lamp flame—a quarter-inch tube with an eighth-

* Cut a nick, with a large file, in the spot where you wish to start a crack near the bottom, then heat a rod or poker nearly red hot, place it on the nick; a crack starts; draw your hot iron and the crack will follow; when nearly cracked around, pull the bottom off. A glass chimney may be used, but it is rather too small to contain sufficient iron sulphide.

inch aperture is sufficiently large and is easily bent. Take an inch rod of iron, let the blacksmith heat it white hot and press it into a small roll of brimstone; this will give you iron sulphide —you need it in pieces as large as bullets; it melts readily against the brimstone. Place some cotton in the neck of the bottle, and, having fitted a plug of wood with holes in it for the bottom of the bottle, invert the bottle and fill it half full of iron sulphide lumps, fasten the wooden plug in the bottom, not very tightly, but tightly in three or four places, so that water can pass freely, and yet the plug be well fixed in. Put the bottle in its place, resting in the jar at *A*, and somewhat loosely fastened. But this must be after you have half filled the jar with a mixture of equal parts common hydrochloric acid and rain water. Sulphuretted hydrogen will form immediately, and if you have made all connections perfectly as in the figure, the gas will pass from this apparatus into the sample of the solution in the beaker, and precipitation will soon take place. The advantage of this apparatus is, that if you tie two little blocks of wood against the side of the rubber tubes *C C*, so as to press the sides together and stop the gas from flowing, the gas forming pushes the water out of the interior glass *D*, and the gas stops forming, but is ready at any moment to begin as soon as the string around the blocks is removed.

Fig. 44.



8. Neutralize the filtrate from the previous experiment and mix it with ammonium sulphide. The precipitate formed, which may be termed *D*, is washed out with water, containing ammonium sulphide and tested according to 10. *Magnesium* may also be contained in the filtrate.

9. To determine *magnesium* evaporate a small quantity of

the filtrate obtained in 8, and add some *sodium phosphate* and *ammonia*. If the solution contains magnesium, a crystalline precipitate of ammonium-magnesium phosphate is formed, which is insoluble in ammoniacal water.

10. Pour dilute hydrochloric acid over the precipitate *D* (from 8). If a black residue—consisting of *sulphides of nickel and cobalt*—which may be termed *E*, is formed, it is filtered off and further tested according to 11. Boil the filtrate until the sulphuretted hydrogen is completely driven off, then compound it with nitric acid, boil again, and evaporate. Now compound with strong alkaline lye in excess, boil and filter. The precipitate, which may be termed *F*, is analyzed according to 12. The filtrate may contain zinc or alumina. Both are determined according to 13.

11. The residue *E* (from 10) is dissolved in hydrochloric acid, a few drops of nitric acid are added and the solution is evaporated nearly to dryness. By adding some *sodium nitrate* and *acetic acid*, and after standing for some time in the heat, a yellow precipitate is formed if *cobalt* be present. After 12 hours filter off and compound the filtrate with caustic soda. *Nickel* is present when a greenish precipitate is formed, which does not completely dissolve in the excess of the precipitating agent.

12. A portion of the precipitate *F* (from 10) is dissolved in hydrochloric acid and a sample of it tested:

a. With potassium ferrocyanide for *iron*.

b. Melt another sample with *potassium carbonate* and *potassium chlorate*, and boil the melted mass with water. If *chromium* was present it has been converted into chromic acid (yellow solution), and can be readily recognized by compounding the solution with *sugar of lead*. If chromium is not found, a portion of the sample is tested with the blow-pipe for *manganese*.

c. If chromium was found a portion of the hydrochloric acid solution is neutralized with *potassium carbonate*, com-

pounded with caustic soda in excess, and the precipitate tested for *manganese* and the filtrate for *zinc*, according to 13.

13. Moisten the solution to be tested for *manganese* upon a platinum-sheet with some soda and a trace of saltpeter, and let the flame of the blow-pipe act upon it. If the solution contains manganese a green paste is obtained, which on cooling turns blue-green. The filtrate from 10 may contain zinc or alumina. Compound a portion of it with sulphuretted hydrogen; a white precipitate (sulphate of zinc) indicates *zinc*. Acidulate another portion with hydrochloric acid, add ammonia in slight excess and warm. *Alumina*, if contained in the solution, is precipitated as aluminium hydrate.

14. The white precipitate *B* (from 4) may contain chloride of silver, chloride of lead, or subchloride of mercury. Treat it with much *water*, whereby chloride of lead is dissolved; the *lead* may then be determined as in 3, with sulphuric acid. Treat the residue with *ammonia*. If complete solution takes place, the residue consists of chloride of silver, and from the solution the *silver* is again precipitated as chloride of silver by nitric acid. A black residue, insoluble in water and ammonia, consists of chlorine and mercury, (subchloride of mercury).

15. The residue which remained by dissolving in nitric acid is warmed in aqua-regia. If a white insoluble powder is separated it generally consists of chloride of silver, more rarely of chloride of lead. Though silver and lead by themselves are soluble in nitric acid, by alloying with the more noble metals they are frequently protected from solution, and may be contained in the residue. They are determined according to 14. A portion of the solution is now mixed with ferrous sulphate solution. A fine brownish separation consists of *metallic gold*. A yellow precipitate produced by sal ammoniac establishes the presence of *platinum*.

If the residue *A* consists of a white powder it is washed

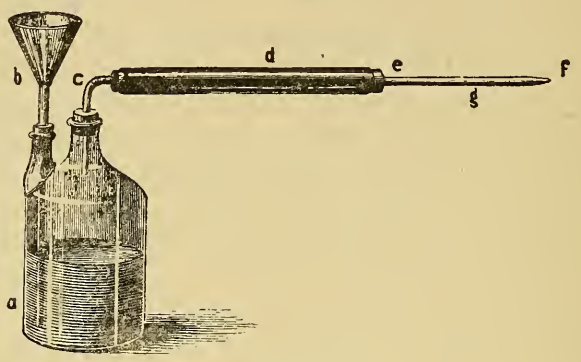
with water and boiled in a flask with tartaric acid. If it is soluble it consists of oxide of antimony; if insoluble it contains *tin*.

16. The precipitate *C* (from 7) obtained with sulphuretted hydrogen contains a number of metallic sulphides, a portion of which—antimony, arsenic, tin, gold, platinum—is dissolved by ammonium sulphide. The residue is boiled with dilute nitric acid and dissolves thereby, separating flaky sulphur, which floats upon the solution. If a portion remains undissolved it consists of *oxide of mercury*. From the filtered solution separate the lead by means of sulphuric acid (see 3), and after settling, filter, and mix with ammonia. A precipitate indicates *bismuth;* a blue coloration *copper*. Evaporate the solution completely, add some acetic acid and water, and precipitate the copper with sulphuretted hydrogen. *Cadmium*, if present, is precipitated as sulphide of cadmium, and hence the precipitate has to be treated with boiling sulphuric acid. The sulphide of cadmium is dissolved, while sulphide of copper remains undissolved. If the alloy contains cadmium *yellow sulphide of cadmium* is precipitated from the filtrate by sulphuretted hydrogen.

17. Some alloys contain arsenic, it being also found as an impurity in many metals. To complete the analysis, a test for arsenic must therefore be made. Marsh's apparatus is used for this purpose. It consists of a flask *a* (Fig. 45), in which hydrogen gas is developed from chemically pure zinc and dilute pure sulphuric acid. The tube *c* ends in a wide glass tube *d*, which is filled with calcium chloride for drying the gas. The gas escapes through the smaller tube *e*, running to a point at *f*. If now through the funnel *b* a few drops of the metallic solution are brought into the apparatus, the flame of hydrogen will acquire a *blue* coloration if the solution contains arsenic, and a white smoke of arsenious acid will rise from it. The arsenietted hydrogen formed is very poisonous, a few bubbles of it being sufficient to

cause death. If a piece of glass or porcelain is depressed upon the flame it will acquire a metallic mirror of arsenic. The metallic mirror, however, is not an infallible test, since *antimony* produces the same phenomenon. To ascertain

Fig. 45.



whether arsenic or antimony has to be sought for in the metal, drop a little solution of calcium chloride upon the metallic mirror; arsenic is immediately dissolved, while antimony remains unchanged.

Testing brass.—Evaporate the alloy with nitric acid to dryness, take up with a few drops of nitric acid and with water, filter the residue (*oxide of tin*, with or without *oxide of antimony*), precipitate from the filtrate *lead* with sulphuric acid, from the filtrate of sulphate of lead *copper* with sulphuretted hydrogen, from the oxidized filtrate any *iron* present by ammonia and ammonium chloride, and from another portion of the filtrate by potash lye *manganese* to be tested with saltpetre and soda. For establishing a content of *antimony* in the separated oxide of zinc dissolve the latter in as little hydrochloric acid as possible, bring the fluid upon a platinum sheet and a small piece of zinc, whereby, if antimony is present, a dark-brown to black stain is formed. In the absence of tin and in the presence of small quantities of antimony in solution, super-

saturate the solution in nitric acid with potash lye, heat with solution of potassium bisulphide, filter, and precipitate from the filtrate with hydrochloric acid sulphide of antimony as well as sulphide of arsenic; dissolve the precipitate in fuming hydrochloric acid and test upon a platinum sheet with zinc for antimony. Dissolve the residue (sulphide of arsenic), insoluble in the acid, in a little hydrochloric acid and potassium chlorate, heat until the odor of chlorine disappears, and test for arsenic in Marsh's apparatus, Fig. 45. A content of *bismuth* may be detected by dissolving a larger quantity of alloy in as little dilute hydrochloric acid of 1.12 specific gravity as possible, heating carefully, filtering off separated oxide of tin, precipitating bismuth from the filtrate with ammonia, dissolving the precipitate in greatly dilute hydrochloric acid and allowing the solution to fall drop by drop into a large quantity of water, whereby a white turbidity appears.

Testing Britannia metal. Good qualities of Britannia metal, which can be rolled, contain 90 to 93 per cent. tin, and, at the utmost, 10 per cent. antimony and 0 to 3 per cent. copper, while inferior qualities contain less than 85 per cent. tin. Hence, the principal point would be the determination of the content of tin. For the purpose of testing whether, besides tin and antimony, other metals are present, oxidize with nitric acid, supersaturate with ammonia, add ammonium sulphide and heat. If the resulting solution is not clear, other metals are present.

Testing bronze. Decompose the bronze with nitric acid, evaporate to dryness, heat the residue with water, filter off the *stannic acid*, separate from the filtrate *lead* by means of alcohol and sulphuric acid, and from the filtrate thereof *copper* by means of sulphuretted hydrogen; filter, add to the filtrate, freed from sulphuretted hydrogen by heating, some potassium chlorate, precipitate *iron* with ammonia in excess, and from filtrate, supersaturated with acetic acid, *zinc* with sulphuretted hydrogen; supersaturate the filtrate

thereof with ammonia and precipitate *manganese* with ammonium sulphate. A test for arsenic may be made in Marsh's apparatus by dissolving a sample in hydrochloric acid, with addition of potassium chlorate and heating the fluid to be tested until the chlorine odor disappears. A very sensitive test, according to Gutzeit, is as follows: Pour over zinc in a test-tube hydrochloric or sulphuric acid, add the solution to be tested for arsenic, close the mouth of the tube with a cotton stopper, place filtering paper over the latter and bring upon the center of the paper a drop of a solution of nitrate of silver in equal parts of water. In the presence of arsenic the moistened place acquires, first below and then on top, a lemon-yellow color, a brown-black ring being at the same time formed on the periphery, which gradually extends towards the center and finally disperses the yellow coloration. In the presence of much arsenic the yellow coloration is only transitory. *Antimony* gives only a dark brown-red ring on the periphery, while in the presence of much antimony the interior space of the ring appears gray-white. To detect *phosphorus* precipitate from the solution in aqua-regia, copper and tin with sulphuretted hydrogen, supersaturate the filtrate with ammonia, precipitate iron, zinc and manganese with ammonium sulphate, and from the filtrate thereof, ammonium-magnesium phosphate with ammonium chloride, magnesium chloride and ammonia.

Testing German silver.—The quality of German silver being dependent on the content of nickel, is recognized by its color, a yellowish coloration indicating an inferior product. A content of arsenic is detected by dissolving a sample of the alloy in nitric acid, evaporating with sulphuric acid until the nitric acid is expelled, diluting with water and testing in Marsh's apparatus, Fig. 45, or according to Gutzeit's method given above.

To test gold-ware.—When a sample of the alloy cannot be taken for a chemical test, the touchstone forms a con-

venient means of examination. It consists of a species of black basalt obtained chiefly from Silesia. If a piece of gold be drawn across its surface a golden streak is left which is not affected by moistening with nitric acid, whilst the streak left by brass or any similar base alloy would be rapidly dissolved. Experience enables an operator to determine by means of the touchstone nearly the amount of gold present in the alloy, comparison being made with the streaks left by alloys of known composition.

Resistance of a few metals and alloys to calcium hydrate.—Filings and turnings of the metals to be examined in quantities of 77 grains, were left, at a normal temperature to the action of milk of lime with 4 per cent. hydrate for 14 days; they were then separated from the lime solutions by washing until phenolphthaleine showed no longer a red coloration, dried and weighed. The results were as follows:

1. "Saxonia" pure soft lead: loss of weight, 0.811 per cent. The metal was considerably attacked.

2. Antimony regulus: the metal remained entirely unchanged.

3. Lead pipe (with 25 per cent. slag lead): loss of weight, 0.299 per cent.; considerably attacked.

4. Lead plate (12 per cent. slag lead): loss of weight, 0.658 per cent.; considerably attacked.

5. Pure cast iron: increase in weight, 0.014 per cent.; very much corroded.

6. Brass: loss of weight, 0.686 per cent.; considerably attacked.

7. Phosphor-bronze: no alteration.

8. Pure tin: loss of weight, 0.122 per cent.; the metal was but little attacked.

From these results it may safely be concluded that for pumps intended for the conveyance of milk of lime, phosphor bronze or an alloy of tin and antimony is most suitable.

To distinguish tin-foil from lead-foil.—Treat the foil with concentrated sulphuric acid; tin is dissolved, while lead remains undissolved.

To test mercury as to its purity.—Pour nitric acid over a drop of mercury in a dish. If pure, the mercury moves for a moment and then remains quiet and motionless. If it contains foreign metals it commences at once a vigorous circular motion, which is kept up until the mercury is completely dissolved.

Tin is generally tested as to its purity by breaking it, whereby it gives out a single, crackling sound (the cry of tin). To recognize the nature of impurities dissolve a sample in aqua-regia; *arsenic* and *antimony* are detected by Marsh's apparatus (see p. 503). Mix another portion of the solution with potassium ferrocyanide; a white precipitate indicates the purity of the tin; a blue precipitate generally the presence of *iron*, and a red-brown precipitate that of *copper*. Lead may be detected by the addition of sulphuric acid or Glauber's salt.

Soft solders are tested in the same manner. They should contain only tin and lead. Some soft solders contain bismuth, which is detected by diluting the solution (see under 2, p. 498).

To detect lead in tin.—Make a solution of potassium bichromate in water. Next apply some acetic acid to the tin to be tested, which will produce a whitish coating. Then apply some of the potassium bichromate solution, and if the whitish coating turns yellow the tin contains lead, and the more the yellower the coating becomes.

White metals should always be tested with Marsh's apparatus, Fig. 45. If the metallic mirror is only partially dissolved by chloride of lime, the sample contains *arsenic* and *antimony*. The other constituents are found in the manner already stated.

Nickel has only to be tested for copper, iron and cobalt. The manner of determining copper has been given under 5,

p. 499. Iron can be recognized by its reaction with potassium ferro-cyanide. To determine the presence of *cobalt*, dissolve the metal in hydrochloric acid, dilute the solution with water, and write with a clean goose-quill upon a strip of white paper. After drying heat the writing; if it appears emerald-green to blue-green the solution contains cobalt. For other methods see under 11, p. 501.

APPENDIX.

COLORING OF ALLOYS.

In many cases alloys are provided with a coating, the object being either to increase their beauty or to protect them from oxidation and discoloration. Articles of ordinary alloys, which are not to be exposed to the fire, are frequently only provided with a coating of lacquer consisting usually of a solution of shellac in alcohol, that made with "stick lac" being as a rule, the best. The lacquer may be colored by any permanent transparent alcoholic solution giving the desired tint. Dragon's blood, red sanders, or annotto is generally used for red, and gamboge, sandarac, saffron, turmeric, or aloes for yellow; these coloring matters may be replaced by aniline colors. In applying the lacquer care should be had to keep the article to be lacquered warm and of uniform temperature, and to perform the work as quickly and smoothly as possible. Keep the lacquers in well-stoppered bottles, best of opaque material. For use pour them into dishes of convenient size, and apply them with a thin, wide, flat brush. The following is Graham's* table of lacquers:—

*Brass-Founder's Manual, London, 1887.

Number.	Shellac.	Mastic.	Canada balsam.	Spirits of wine.	Pyro-acetic ether.	Spirits of turpentine.	Turpentine varnish.	Simple pale lacquer.	Dragon's blood.	Annotto.	Sanders.	Turmeric.	Gamboge.	Saffron.	Cape aloes.	Sandarac.	
	oz.	dr.	dr.	pt.	oz.	dr.	oz.	pt.	dr.	dr.	gr.	dr.	dr.	dr.	dr.	dr.	
1	4	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	Strong simple.
2	1	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	Simple pale.
3	1	—	—	1	—	—	—	—	—	—	—	—	1	—	3	—	Fine pale.
4	1	—	—	1	—	—	—	—	—	—	—	1	1	2	—	—	"
5	1	—	—	2	—	—	—	—	1	1	—	—	16	4	—	8	"
6	2	—	—	2	—	—	—	—	1	8	—	32	—	—	—	8	Plate gold.
7	2	—	—	1	—	—	—	—	—	—	—	—	2	—	4	—	Pale yellow.
8	5	—	—	3	30	—	—	—	—	—	—	—	—	—	—	—	"
9	—	—	—	—	—	—	—	1	—	1	—	4	—	—	—	—	Full yellow.
10	3	—	—	1	—	—	—	—	—	2	—	16	—	2	—	—	Gold.
11	3	—	—	4	—	—	6	—	—	—	—	64	6	—	—	14	"
12	1	—	—	1	—	—	—	—	—	—	—	20	—	—	2	5	"
13	3	—	—	1	—	—	—	—	4	—	—	16	—	—	—	—	Deep gold.
14	3	—	—	1	—	—	—	—	4	—	—	1	—	—	—	—	"
15	3	—	—	1	—	30	—	—	40	—	12	10	—	—	—	—	"
16	—	—	—	—	—	—	—	1	8	32	—	—	—	—	—	—	Red.
17	1	—	—	—	—	—	1	—	8	24	—	—	—	—	—	27	"
18	15	30	30	6	—	—	—	—	20	—	—	60	—	10	—	—	Tin lacquer.
19	—	—	—	—	—	—	—	1	—	—	—	4	1	—	—	—	Green, for bronze.

By coating articles of copper or brass with good fat copal lacquer, and heating after drying until the lacquer commences to smoke, a coat is obtained which protects the articles as well as the tinning against the action of acid liquids.

Articles of copper and bronze exposed for a long time to the action of the air acquire a beautiful brown or green color, which considerably contributes to their handsome appearance. This color is known as *Aerugo nobilis* (noble rust) or *patina*.

Though there are many agents by means of which a layer of patina can be produced upon the bronze, the coating thus obtained cannot compare, as regards beauty and durability, with the genuine patina.

In order to obtain a coating similar to genuine patina (see p. 260) upon objects of copper and of bronze and brass, they are repeatedly brushed with solution of sal ammoniac in vinegar; the efficiency of the solution is accelerated by the addition of verdigris. A still better effect

is produced by a solution of 9 drachms of sal ammoniac and 2¼ drachms of potassium binoxadate (salt of sorrel) in 1 quart of vinegar. When the first coating is dry, wash the article and repeat the manipulations, drying and washing after each application, until a *green* patina is formed. It is best to bring the articles after being brushed over with the solution into a hermetically closed box, upon the bottom of which a few shallow dishes containing very dilute sulphuric or acetic acid and a few pieces of marble are placed. Carbonic acid being thereby evolved, and the air in the box being kept sufficiently moist by the evaporation of water, the natural conditions under which genuine patina is formed are produced. If the patina is to show a more *bluish* tone, brush the objects with a solution of 4½ ozs. of ammonium carbonate and 1½ ozs. sal ammoniac in 1 quart of water, to which a small quantity of gum tragacanth may be added.

All shades from the pale-red of copper to a dark chestnut brown can be produced from copper by superficial oxidation. For small objects it suffices to heat them uniformly over an alcohol flame. With large objects a more uniform result is obtained by heating them in oxidizing fluids or brushing them over with an oxidizing paste, the best results being obtained by the application of a paste prepared, according to the darker or lighter shades desired, from 2 parts ferric oxide and 1 part black lead, or 1 part each of ferric oxide and black lead, with alcohol or water. Apply the paste as uniformly as possible with a brush, and place the objects in a warm place (oven or drying chamber). The darker the color is to be the higher the temperature must be and the longer it must act upon the objects. When sufficiently heated the dry powder is removed by brushing with a soft brush, and the manipulation repeated if the object does not show a sufficiently dark tone. Finally, the object is rubbed with a soft linen rag moistened with alcohol, or brushed with a soft brush and a few drops of

alcohol until completely dry, and then with a brush previously rubbed upon pure wax. The more or less dark shade produced in this manner is very warm and resists the action of the air.

Brown color upon copper.—Apply to the thoroughly cleansed surface of the object a paste of verdigris 3 parts, ferric oxide 3, sal ammoniac 1, and sufficient vinegar, and heat until the applied mixture turns black. The object is then washed and dried. By the addition of some blue vitriol the color may be darkened to chestnut brown.

In England a *brown layer of cuprous oxide* upon copper articles is produced as follows: After polishing the articles with pumice powder apply with a brush a paste of 4 parts of verdigris, 4 parts of colcothar (ferric oxide), 1 part of finely rasped horn shavings and a small quantity of vinegar. Dry, heat over a coal fire, wash, and smooth with the polishing stone.

A *brown color* is also obtained by brushing to dryness with a hot solution of 1 part of potassium nitrate, 1 of common salt, 2 of ammonium chloride, and 1 of liquid ammonia in 95 of vinegar. A warmer tone is, however, produced by the method introduced in the Paris Mint, which is as follows: Powder and mix intimately equal parts of verdigris and sal ammoniac. Take a heaping tablespoonful of this mixture and boil it with water in a copper kettle for about twenty minutes and then pour off the clear fluid. To give copper objects a bronze-like color with this fluid, pour part of it into a copper pan; place the objects separately in it upon pieces of wood or glass, so that they do not touch each other, or come in contact with the copper pan, and then boil them in the liquid for a quarter of an hour. Then take the objects from the solution, rub them dry with a linen cloth, and brush them with a waxed brush.

A *red-brown color* on copper is produced in China by the application of a paste of verdigris 2 parts, cinnabar 2, sal ammoniac 5, and alum 5, with sufficient vinegar, heating over a coal fire, washing, and repeating the process.

According to Manduit, copper and coppered articles may be bronzed by brushing with a mixture of castor oil 20 parts, alcohol 80, soft soap 40, and water 40. This mixture produces tones from bronze Barbédienne to antique green patina, according to the duration of the action. After 24 hours the article treated shows a beautiful bronze, but when the mixture is allowed to act for a greater length of time the tone is changed and several different shades of great beauty are obtained. After rinsing, dry in hot sawdust, and lacquer with colorless spirit lacquer.

Copper is colored blue-black by dipping the object in a hot solution of 11¼ drachms of liver of sulphur in a quart of water, moving it constantly. *Blue-gray* shades are obtained with more dilute solutions. It is difficult to give definite directions as to the length of time the solution should be allowed to act, since this depends on its temperature and concentration. With some experience the correct treatment, however, will soon be learned.

The so-called *cuivre fumé* is produced by coloring the copper or coppered objects blue-black with solution of liver of sulphur, then rinsing, and finally scratch-brushing them, whereby the shade becomes somewhat lighter. From raised portions which are not to be dark, but are to show the color of copper, the coloration is removed by polishing upon a felt wheel or bob.

Black color upon copper is produced by a heated pickle of 2 parts of arsenious acid, 4 of concentrated muriatic acid, 1 of sulphuric acid of 66° Bé., and 24 of water.

Matt-black on copper.—Brush the object over with a solution of 1 part platinum chloride in 5 of water, or dip it in the solution. A similar result is obtained by dipping the copper object in a solution of nitrate of copper or nitrate of manganese, and drying over a coal fire. These manipulations are to be repeated until a uniform matt-black is formed.

The *bronze upon French bronze figures* shows all shades

of pale or clay yellow to red-brown, and of red to dark and black-brown. It has a bronze-like appearance and adheres firmly to the metal, *i. e.*, appears to be chemically combined with it. To produce such colorations, solutions of sulphur, combinations of arsenic and antimony have been successfully used. After chasing and pickling the article must be subjected to a thorough washing with water, as otherwise every trace of acid left behind will later on in drying or bronzing penetrate through the seams and produce indelible stripes and stains. The drying of the article must also be done with the greatest care. For applying the solutions a tuft of cotton or a soft, close brush is used. The work is best commenced by first applying a dilute solution of ammonium bisulphide as sparingly as possible, brushing over a certain limited portion of the figure at one time. The quicker and more uniformly this is done the better and more beautiful the bronzing will be. After drying the sulphur separated out is brushed off and a solution of sulphide of arsenic in ammonia applied, the result being a coloration similar to massive gold. The oftener this solution of sulphide of arsenic is applied the browner the color becomes, and a very dark brown can be finally obtained by a solution of sulphide of arsenic in ammonium bisulphide. By solutions of sulphide of antimony in ammonia or ammonium sulphide the coloration becomes reddish, it being possible to produce the most delicate rose-color as well as the deepest dark red. By rubbing certain portions somewhat more strongly a very fine metallic luster is produced. Ammonia or ammonium sulphide redissolves the bronzing, so that places not thoroughly colored can be improved, though in such case it is better to rub off the entire figure with ammonium sulphide. In the same manner as the solutions in ammonia or ammonium sulphide, those in hydrate or sulphide of potassium or sodium can also be used, the latter being in some cases even more advantageous. By pickling the figure the color

of the bronze is changed. If a casting of bronze or brass is left too long in the pickle, the metal becomes coated with a greenish-gray film, which on rubbing with a cloth rag becomes lustrous and adheres firmly. On treatment with the above metallic sulphides this coating acquires a dull-yellow coloration.

Graham's bronzing liquids * have a great range of composition and of application as follows:—

I. *For brass (by simple immersion).*

Number.	Water.	Nitrate of iron.	Perchloride of iron.	Permuriate of iron.	Nitrate of copper.	Tersulphide of arsenic.	Muriate of arsenic.	Potash solution of sulphur.	Pearlash solution.	Cyanide of potassium.	Ferrocyanide of potassium solution.	Sulphocyanide of potassium.	Hyposulphite of soda.	Nitric acid.	Oxalic acid.	
	pt.	dr.	dr.	pt.	oz.	gr.	oz.	dr.	dr.	oz.	pt.	dr.	dr.	dr.	oz.	
1	1	5	—	—	—	—	—	—	—	—	—	—	—	—	—	Brown and every shade to black.
2	1	—	5	—	—	—	—	—	—	—	—	—	—	—	—	" "
3	1	16	—	—	—	—	—	—	—	—	—	—	16	—	—	Brown and every shade to red.
4	1	—	—	—	—	—	—	—	—	—	—	—	16	1	—	" "
5	1	—	—	—	1	—	—	—	—	—	—	—	—	—	1	Brownish-red.
6	—	—	—	—	—	—	—	—	—	—	1	—	—	3	—	" "
7	1	—	—	—	—	—	—	—	—	1	—	—	—	4	—	Dark brown.
8	1	—	—	—	—	30	—	—	6	—	—	—	—	—	—	Yellow to red.
9	1	—	—	—	—	—	—	1	—	—	—	—	—	—	—	Orange.
10	2	—	—	1	—	—	—	—	—	—	—	—	—	—	—	Olive-green.
11	1	—	5	—	—	—	—	—	—	—	—	2	—	—	—	Slate.
12	1	—	—	—	—	—	—	—	—	—	—	—	20	—	—	Blue.
13	1	—	—	—	—	—	1	—	—	—	—	—	—	—	—	Steel-gray.
14	1	—	—	2	—	—	10	—	—	—	—	—	—	—	—	Black.

In the preparation of No. 5 the liquid must be brought to boil and cooled. In using No. 13 the heat of the liquid must not be under 180° F. No. 6 is slow in action, sometimes taking an hour to give good results. The action of the others is usually immediate.

* Brass-Founder's Manual, London, 1887.

II. *For copper* (*by simple immersion*).

Number.	Water.	Nitrate of iron.	Sulphate of copper.	Sulphide of antimony.	Sulphur.	Muriate of arsenic.	Pearlash.	Sulphocyanide of potassium.	Hyposulphite of soda.	Hydrochloric acid.	
	pt.	dr.	oz.	dr.	dr.	dr.	oz.	dr.	oz.	dr.	.
15	1	5	—	—	—	—	—	—	—	—	Brown, and every shade to
16	1	5	—	—	—	—	—	2	—	—	Dark brown-drab. [black.
17	1	—	1	—	—	—	—	—	2	2	" "
18	1	—	—	2	—	—	1	—	—	—	Bright red.
19	1	—	—	—	1	—	1	—	—	—	Red, and every shade to
20	1	—	—	—	—	1	—	—	—	—	Steel-gray, at 180° F. [black.

III. *For zinc* (*by simple immersion*).

Number.	Water.	Nitrate of iron.	Protochloride of tin.	Sulphate of copper.	Muriate of iron.	Muriate of lead.	Pearlash.	Sulphocyanide of Potassium.	Hyposulphite of soda.	Garancine infusion.	Logwood infusion.	
	pt.	dr.	dr.	dr.	dr.	oz.	dr.	dr.	dr.			
21	1	5	—	—	—	—	—	—	—	—	—	Black.
22	1	—	1	—	—	—	—	—	—	—	—	"
23	1	—	1	—	—	—	—	1	—	—	—	Dark-gray.
24	2	—	—	1	1	*	—	—	—	—	—	"
25	—	—	—	—	—	—	—	—	—	—	—	"
26	2	—	—	—	1	—	—	—	—	—	—	Green-gray.
27	—	—	—	—	—	—	—	—	—	*	—	Red (boil).
28	1	—	—	4	—	—	4	—	—	—	—	Copper color.
29	1	—	—	8	—	—	—	—	8	—	—	" (with agita-
30	—	—	—	—	—	—	—	—	—	—	*	Purple (boil). [tion).

To provide articles of brass or bronze with a very lustrous gray or black coating, the tendency of certain metallic salts of forming gray or black combinations with sulphur is utilized. For *gray* dip the article first into a very dilute

* Made to the consistency of cream.

solution of acetate of lead, or for *black* into a solution of sulphate of copper, and after drying into a hot dilute solution of hyposulphite of soda.

By using the solutions in a very dilute state the articles acquire a peculiar, iridescent appearance similar to soap-bubbles, and it is also due to the same cause. It is well known from the teachings of physics that many bodies show, when in very thin layers, the peculiar color-phenomenon termed iridescence, and this is also produced by a very thin layer of sulphide of lead or sulphide of copper. By repeating the treatment of the article in very dilute solutions, the iridescence passes into a red, brownish, or violet coloration. It is impossible to give exact proportions for the production of these colors, the success of the coloration depending largely on the skill of the operator.

Very beautiful, but not very permanent, iridescent coatings can be produced by placing the bright metal in a bath of a heavy metal decomposable by the galvanic current, touching it for a moment with the negative pole of the battery, taking it out, rinsing off, and drying. The metal will show all the colors of the rainbow, but the coating is so delicate that it must be protected by immediately dipping the article after drying into a quick-drying lacquer.

There are many means of providing small articles of brass with a coating of one color, various liquids being, for instance, used to produce determined shades of color upon brass buttons. For a pure *golden-yellow*, the buttons are dipped for a few seconds in a perfectly neutral (absolutely free from acid) solution of acetate of copper. A *gray-green* shade is produced by repeatedly dipping them in a dilute solution of chloride of copper and drying after each dipping. A violet tint is obtained by heating the buttons to a temperature at which oxidation does not take place, and rubbing them with a tuft of cotton dipped in a solution of antimony in hydrochloric acid.

For the production of the *beautiful gold color* possessed

by many French articles of brass the following process may be used: Dissolve 1.76 ounces of caustic soda and 1.41 ounces of milk sugar in 2.11 pints of water. Boil the solution for fifteen minutes, and after taking it from the fire compound it with 1.41 ounces of cold concentrated solution of sulphate of copper. The red precipitate of cuprous oxide, which is immediately formed, deposits on cooling upon the bottom of the vessel. The polished articles resting upon a wooden sieve are then placed in the vessel containing the solution. After about a minute the sieve is taken out in order to ascertain how far the operation has progressed; it is then replaced, and at the end of the second minute the golden color is generally dark enough. The sieve is then taken out, and the articles after washing are dried in sawdust. By allowing the articles to remain for a longer time in the solution they acquire in a short time a greenish tint, which soon becomes yellow and then bluish-green, until finally the iridescent colors are formed. In order to obtain a uniform coloration it is necessary to produce the color slowly, which is best attained at a temperature of from 132° to 136° F. The bath can be repeatedly used and kept for a long time in well-stoppered bottles. If partially exhausted, it can be restored by an addition of 5.64 drachms of caustic soda, sufficient water to replace that lost by evaporation, heating to the boiling-point, and finally adding 14.11 drachms of cold solution of sulphate of copper.

To produce *a beautiful silver color* upon brass, proceed as follows: Dissolve in a well-glazed vessel 1½ ounces of pulverized cream of tartar and 2.25 drachms of tartar emetic in 2.11 pints of hot water, and add to the solution 1¾ ounces of hydrochloric acid, 4⅓ ounces of granulated, or, still better, pulverized tin, and one ounce of pulverized antimony. Dip the article to be coated in the solution heated to the boiling-point. After boiling one-quarter to one-half an hour, they will be provided with a beautiful lustrous coating which is hard and durable.

Browning liquid for copper.—Add acetic acid to 11 drachms of spirit of sal ammoniac until blue litmus paper dipped in the liquid turns red. Then add 5½ drachms of sal ammoniac and sufficient water to make 2.11 pints. With the solution thus obtained repeatedly moisten the copper surfaces, rubbing after each application until the desired brown tint is produced.

For coloring brass Ebermayer, of Nürnberg, gives the following directions: (1) 8 parts of sulphate of copper, 2 of sal ammoniac, and 100 of water give by boiling a greenish color. (2) 10 parts of potassium chlorate, 10 of sulphate of copper, and 1000 of water give by boiling a brown-orange to cinnamon-brown color. (3) By dissolving 8 parts of sulphate of copper in 100 of water, and adding about 100 parts of caustic soda until a precipitate is formed, and boiling the articles in the solution, they acquire a greenish-brown color, which can be made darker by the addition of rouge. (4) With 50 parts caustic soda, 50 of sulphide of antimony, and 500 of water, and boiling, a light fig-brown color is obtained. (5) Boil 29 parts of sulphate of copper, 20 of hyposulphite of soda, and 10 of cream of tartar in 400 of water. The brass first acquires a rose-color, and then a blue color. By adding 20 parts of ammonio-ferric sulphate and 20 of hyposulphite of soda, the colors change from yellow to rose-color, and blue; after the latter yellow again makes its appearance, and finally a beautiful gray is formed. (6) 400 parts of water, 20 of potassium chlorate, and 10 of nickel salt give, after boiling for some time, a brown color, which is, however, not formed if the sheet has been pickled. (7) 250 parts of water, 5 of potassium chlorate, 2 of carbonate of nickel, and 5 nickel salt give, after boiling for some time, a brown-yellow color playing into a magnificent red. (8) 250 parts of water, 5 of potassium chlorate, and 10 of nickel salt give a beautiful dark brown. (9) 250 parts of water, 5 of orpiment, and 10 of crystallized soda give at first a beautiful red which passes into blue, then into pale blue,

and finally becomes white. (10) 250 parts of water, 5 of nickel salt, 5 of sulphate of copper and 5 of potassium chlorate give a well-covering yellow-brown color. (11) 100 parts of water, 1 of liver of sulphur, and 5 of ammonia. The articles being allowed to lie in a closed vessel finally acquire a very beautiful blue color.

Coloring of soft solders.—For giving the solder used in soldering copper the same color as the latter, prepare first a saturated solution of pure sulphate of copper and apply it to the solder. By then touching the solder with an iron or steel wire the latter becomes covered with a film of copper, which can be augmented as much as desired by repeated moistening with the solution of sulphate of copper and touching with the wire. If the soldering is to show a yellow color, mix 1 part of saturated solution of sulphate of zinc with 2 parts of solution of sulphate of copper, apply the mixture to the coppered place and rub the latter with a zinc rod. If the soldered place is to be gilded, copper it as above described, then coat it with a solution of gum or isinglass, and strew bronze powder upon it. This forms a surface which, when the gum is dry, can be polished.

Bronzing of copper, bronze-metal, and brass.—Black bronzing is produced by brushing the metals with dilute nitric acid containing a small quantity of silver in solution, and blazing off over the fire. This operation is repeated if after again brushing the articles with the acid and blazing off, the color is not sufficiently deep. Nitric acid which has been used for dissolving fine silver and then poured off is most suitable for the purpose. A bismuth solution may also be used for coloring the above-mentioned black; after the operations they are coated with lacquer. Brass may be bronzed black as follows: Dissolve copper in an excess of nitric acid, dilute the resulting liquid with a large quantity of rain water, apply it to the warmed brass, allow to dry in a warm place, and finally rub with a brush or with leather. Or amalgamate the brass by brushing it with solution of

mercurous nitrate, and convert the mercury upon the surface into black sulphide of mercury by potassium sulphide solution.

Brown bronze color is produced in the same manner as black, only besides silver the nitric acid must contain copper. Another method is as follows: Dissolve 1 oz. of sal ammoniac and ⅓ oz. of oxalic acid in ½ pint of water and brush the metal several times with the solution. Sulphuretted hydrogen will also produce a brown color. Dissolve liver of sulphur in 30 parts of water, pour the solution into shallow earthen-ware vessels and place the latter in a room protected from draught. Put the articles to be bronzed near the vessels. The object is still more rapidly attained by placing the articles over the vessels containing the liver of sulphur solution. This method of bronzing is especially suitable for articles soldered with soft solder which for that reason cannot be exposed to the fire.

Red-brown or copper-brown upon copper is produced by brushing the articles with a paste-like bronze consisting of a triturated mixture of horn shavings 1 part, verdigris 4, rouge 4 and some vinegar, or by placing them in a liquid bronze prepared as follows: Boil a solution of verdigris 2 parts, and sal ammoniac 1 in vinegar, remove the scum, dilute with water, allow to settle, pour off the supernatant liquid, boil again in a porcelain dish and quickly pour it over the copper articles. The liquid should be much diluted, the metallic articles carefully freed from grease, and rest upon a wooden grate in a vessel which is immediately placed over the fire and the fluid brought to the boiling point; finally rinse in clean water.

Green bronze color is produced as follows: Dissolve a mixture of sal ammoniac ½, argol 1 oz., and common salt 2 ozs. in ½ pint of vinegar. To this solution add 2¾ ozs. of cupric nitrate solution, brush the articles with the resulting liquid and allow to dry.

Coloring of zinc.—The direct coloring of zinc, according

to existing directions, does not yield satisfactory results and it is therefore advisable to first copper the zinc and then color the coppering. Experiments in coloring zinc *black* with alcoholic solution of chloride of antimony according to Dullos's process gave no useful results. Puscher's method is better. According to it the objects are dipped in a boiling solution of 5 ozs. of pure green vitriol and 3 ozs. of sal ammoniac in 2½ quarts of water. The loose black precipitate deposited upon the objects is removed by brushing, the objects again dipped in the hot solution, and then held over a coal fire until the sal ammoniac evaporates. By repeating the operation three or four times a firmly adhering black coating is formed.

Gray, yellow, brown to black colors upon zinc are obtained by bringing the articles into a bath which contains 6 to 8 quarts of water, 3½ ozs. of nickel-ammonium sulphate; 3½ ozs. of blue vitriol and 3½ ozs. of potassium chlorate. The bath is to be heated to 140° F. By increasing the content of blue vitriol a dark color is obtained, and a lighter one with the use of a larger proportion of nickel salt. The correct proportions for the determined shades will soon be learned by practice. When colored, the articles are thoroughly rinsed, dried, without rubbing, in warm sawdust, and finally rubbed with a flannel rag moistened with linseed oil, whereby they acquire deep luster, and the coating becomes more durable.

A sort of *bronzing* on zinc is obtained by rubbing it with a paste of pipe-clay to which has been added a solution of 1 part by weight of crystallized verdigris, 1 of tartar, and 2 of crystallized soda.

Red-brown on zinc.—Rub with solution of chloride of copper in liquid ammonia.

Yellow-brown shades on zinc.—Rub with solution of chloride of copper in vinegar.

Browning gun barrels.—Apply a mixture of equal parts of butter of antimony and olive oil. Allow the mixture to

act for 12 or 14 hours, then remove the excess with a woolen rag, and repeat the application. When the second application has acted for 12 to 24 hours, the iron or steel will be coated with a bronze-colored layer of ferric oxide with antimony, which resists the action of the air, and may be made lustrous by brushing with a waxed brush.

A lustrous black on iron is obtained by the application of solution of sulphur in spirits of turpentine prepared by boiling upon the water-bath. After the evaporation of the spirits of turpentine a thin layer of sulphur remains upon the iron, which on heating the article immediately combines with the metal.

A lustrous black is also obtained by freeing the iron articles from grease, pickling, and after drying, coating with sulphur balsam,* and burning in at a dark-red heat. If pickling is omitted, coating with sulphur balsam and burning-in must be twice or three times repeated.

The same effect is produced by applying a mixture of three parts flower of sulphur, and one part graphite with turpentine and heating in the muffle.

According to Böttger a durable *blue* on iron and steel may be obtained by dipping the article in a ½ per cent. solution of red prussiate of potash mixed with an equal volume of a ½ per cent. ferric chloride solution.

A brown-black coating with bronze luster on iron is obtained by heating the bright iron objects and brushing them over with concentrated solution of potassium bichromate. When dry, heat them over a charcoal fire, and wash until the water running off shows no longer a yellow color. Repeat the operation twice or three times. A similar coating is obtained by heating the iron objects with a solution of 10 parts by weight of green vitriol and 1 part of sal ammoniac in water.

* Sulphur dissolved in linseed oil.

To give iron a silvery appearance with high luster.— Scour the polished and pickled iron objects with a solution prepared as follows: Heat moderately 1½ ozs. of chloride of antimony, 0.35 oz. of pulverized arsenious acid, 2.82 ozs. of elutriated bloodstone with 1 quart of 90 per cent. alcohol upon a water-bath for half an hour. Partial solution takes place. Dip into this fluid a tuft of cotton and go over the iron portions, using slight pressure. A thin film of arsenic and antimony is thereby deposited, which is the more lustrous the more carefully the iron has previously been polished.

On tin a bronze-like patina may be produced by brushing the object with a solution of 1¾ ozs. of blue vitriol and a like quantity of green vitriol in 1 quart of water, and moistening, when dry, with a solution of 3½ ozs. verdigris in 10½ ozs. of vinegar. When dry polish the object with a soft waxed brush and some rouge. The coating thus obtained is, however, not very durable, and must be protected by a coat of lacquer.

Warm sepia-brown tone upon tin and its alloys. Brush the object over with a solution of 1 part of platinum chloride in 10 parts of water, allow the coating to dry, then rinse in water, and after again drying, brush with a soft brush until the desired brown luster appears. The coating is quite durable.

Oxidizing silver. A blue-black color is produced by placing the articles in a solution of liver of sulphur diluted with spirits of sal ammoniac. Allow to remain until the desired dark tone is produced, then wash, dry and polish.

A brownish tint is obtained by using a solution of equal parts of sulphate of copper and sal ammoniac in vinegar.

A yellow color is imparted to silvered articles by immersion in a hot concentrated solution of chloride of copper, rinsing and drying.

Recovery of Waste Metals.

Gold. Besides dust, the sweepings accumulating in gold workers' shops contain gold and silver as well as other metals alloyed with the gold or silver. To obtain the gold and silver proceed as follows:

Burn the sweepings, with the addition of some saltpetre, in a red-hot crucible, lixiviate the residue with water, dry it, and melt it with an addition of 2 per cent. of dehydrated borax. Dissolve the metallic mass thus obtained in aqua regia. The precipitate formed thereby consists of chloride of silver, and is worked into silver. The solution in aqua regia is then evaporated until it commences to become viscous. It is now diluted with water, and a bright sheet of copper immersed in the fluid whereby the gold in solution separates in the form of a brown powder, which is filtered off, washed, dried, and melted with a small quantity of borax, the product obtained being chemically pure gold. The precipitate of chloride of silver, mentioned above, is filtered off, thoroughly washed with water, and brought into a vessel. Water compounded with 10 per cent. of hydrochloric acid is then poured over it, and a sheet of zinc immersed in the fluid. After some time the chloride of silver is thereby converted into a gray powder of metallic silver, which is filtered off, washed with distilled water, dried, and melted with a small quantity of borax.

The water used by the workmen in gold-workers' shops for washing their hands contains gold and silver. The water is collected in a tank, and from time to time drawn off from the sediment. When a sufficient quantity of the latter has accumulated, it is dried, the residue mixed with 5 per cent. of saltpetre, the mass decrepitated in a red-hot crucible, washed with water, dried, and melted with a small quantity of borax. The metallic mass thus obtained is treated in the same manner as that from the sweepings.

For the *recovery of gold from coloring baths* a solution of two parts by weight of ferrous sulphate (green vitriol)

in 18 parts by weight of hot water, may be used. The waste water as well as the exhausted coloring salts should be preserved in a large stone-ware jar kept for the purpose. Add the solution of ferrous sulphate to the contents of the jar and stir well, when the gold will begin to precipitate. Repeat this each time after coloring, and as the jar becomes full add a little more ferrous sulphate and thoroughly stir the contents. If this produces no effect upon the solution the gold has all been precipitated. Now allow to settle, and then draw off the supernatant water, being very careful not to disturb the precipitate, which forms a dark spongy mass at the bottom. Wash the precipitate several times with hot water to free it from every trace of acid, then dry it in an iron vessel, and then fuse it in a covered crucible with a flux, which for 1 lb. of prepared sediment consists of carbonate of potash, 8 ozs.; common salt, 4 ozs.; common bottle glass, 4 ozs. Reduce all the ingredients to a fine powder and mix them well together. In order to effect a complete reduction of the gold great heat is required.

According to Boettger, *gold may be recovered from auriferous fluids* by the following process: Heat the fluid in a porcelain vessel to the boiling-point, and then mix it with sodium stannate solution. Keep the mixture boiling until all the gold—in combination with tin—is separated in the form of a fine precipitate of an intense black color. This precipitate is washed and then dissolved in aqua-regia. The solution thus obtained consists of a mixture of chloride of gold and chloride of tin. By slightly evaporating the solution, diluting with distilled water, mixing with a sufficient quantity of potassium and sodium tartrate (Rochelle salt), and heating, every trace of gold is precipitated in the form of a very delicate, brownish powder, while the tin remains in solution.

Recovery of gold from old cyanide solutions.—Evaporate the solution to dryness, reduce the residue to a fine powder, mix it intimately with an equal weight of litharge (oxide of

lead), and fuse at a strong heat. From the resulting button of gold and lead alloy, the lead is extracted by warm nitric acid, the gold remaining behind as a loose, spongy mass.

By the *wet process* the gold may be recovered from old cyanide solutions as follows: Acidulate the solution, which contains gold, silver and copper, with hydrochloric acid, whereby hydrocyanic acid is disengaged. This gas being extremely poisonous, the operation should be carried on in the open air, or where there is a good draught or ventilation to carry off the fumes. A precipitate consisting of the cyanides of gold and copper and chloride of silver is formed. This is well washed and boiled in aqua-regia, where the gold and copper are dissolved as chlorides, while the chloride of silver is left behind. The solution containing the gold and copper is evaporated nearly to dryness in order to remove the excess of acid, the residue is dissolved in a small quantity of water, and the gold precipitated therefrom as a brown metallic powder by the addition of ferrous sulphate (green vitriol). The copper remains in solution.

Finely divided zinc—so-called zinc dust—is an excellent agent for precipitating gold in a pulverulent form from old cyanide solutions. By adding zinc dust to an exhausted gilding bath and thoroughly shaking or stirring from time to time, all the gold is precipitated in two or three days. The quantity of zinc required for the precipitation depends of course on the quantity of gold present, but, generally speaking, ½ lb. or at the utmost 1 lb. of zinc dust will be required for 100 quarts of exhausted gilding bath. The pulverulent gold obtained is washed, treated first with hydrochloric acid to remove adhering zinc dust, and next with nitric acid to free it from silver and copper.

Separating silver.—Dissolve the alloy or metal containing silver in the least possible quantity of nitric acid. Mix the solution with a large excess of ammonia and filter into a tall glass cylinder provided with a stopper. Introduce

into the liquid a bright strip of copper, which should be long enough to project above the liquid. Pure metallic silver will be quickly separated. Reduction is complete in a short time, and the reduced silver is then washed first with ammoniacal solution and next with distilled water. The more ammoniacal and concentrated the solution, the more rapid the reduction. The strip of copper should not be too thin, as it is considerably attacked, and any little particles which might separate from a thin sheet would contaminate the silver. Any accompanying gold remains behind during the treatment of the metal or alloy with nitric acid; chloride of silver, produced by impurities in the nitric acid is taken up by the ammoniacal solution like the copper, and is also reduced to the metallic state, and whatever other metal is not left behind, oxidized by the nitric acid, is separated as hydrate on treating with ammonia. Any arseniate which may have passed into the ammoniacal solution is not decomposed by the copper.

Recovery of silver from old cyanide solutions.—The solution may be evaporated to dryness, the residue mixed with a small quantity of calcined soda and potassium cyanide and fused in a crucible, whereby metallic silver is formed which, when the heat is sufficiently increased, will be found as a button upon the bottom of the crucible; or if it is not desirable to heat to the melting point of silver, the fritted mass is dissolved in hot water, and the solution containing the soda and cyanide quickly filtered off from the metallic silver.

According to the *wet method* the old cyanide solution is strongly acidulated with hydrochloric acid, observing the precaution to provide for the effectual carrying-off of the hydrocyanic acid liberated as given under gold. Remove the precipitated chloride of silver and cyanide of copper by filtration and after thorough washing, transfer it to a porcelain dish and treat it, with the aid of heat, with hot hydrochloric acid, which will dissolve the cyanide of copper.

The resulting chloride of silver is then reduced to the metallic state by mixing it with four times its weight of crystallized carbonate of soda and half its weight of pulverized charcoal. The whole is made into a homogeneous paste which is thoroughly dried, and then introduced into a strongly heated crucible. When all the material has been introduced the heat is raised to promote complete fusion and to facilitate the collection of the separate globules of silver into a single button at the bottom of the crucible, where it will be found after cooling. If granulated silver is wanted, pour the metal in a thin stream, and from a certain height, into a large volume of water.

Utilization of nickel waste.—For the utilization of waste from rolled and cast nickel anodes, and of the nickel sand gradually collecting upon the bottoms of vats used in plating, the following method is recommended: Wash the waste repeatedly in clean, hot water, and then boil in dilute sulphuric acid (1 part acid to 4 parts water) until the water poured upon the waste is no longer clouded by it. Then pour off the liquid, and treat the waste or sand with concentrated nitric acid. This must be done very carefully, and a capacious porcelain vessel should be used to prevent the solution from running over. When the solution is sufficiently concentrated, so that it contains little free acid, it should be filtered and slowly evaporated to dryness over a water-bath. The product is nickel nitrate. This nickel nitrate is dissolved in hot distilled water, and the solution precipitated with caustic soda carefully and gradually added. The precipitate of hydrated nickel oxide is then carefully filtered and washed, and next treated with dilute sulphuric acid with the assistance of heat until solution has taken place. The solution is concentrated by evaporation, and an excess of concentrated solution of ammonium sulphate is added. The precipitate is the double sulphate of nickel and ammonium, or Adams' nickel-plating salt, which is commonly used for nickel-plating.

Recovery of copper.—In works where great quantities of copper are operated upon, it is advantageous to recover the metal dissolved in the cleaning baths, which can be done by an easy and inexpensive process. All the liquids holding copper are collected in a large cask filled with wrought or cast-iron scraps. By the contact of the copper solution with the iron a chemical reaction immediately takes place, by which the iron is substituted for the copper to make a soluble salt, while the copper falls to the bottom of the cask as a brown powder. The cask should be of sufficient capacity to hold all the liquids employed in a day's work. The liquids are decanted every morning. The old iron scrap is generally suspended in a wicker basket near the top of the liquid, and by occasionally moving it about in the liquid, the metallic powder of copper alone falls to the bottom of the cask. The copper thus obtained is quite pure, aud by calcining it in contact with the air a black oxide of copper is obtained.

To separate silver from copper. Boil the metal in a mixture of sulphuric acid, nitric acid and water, of each 1 part, until it is completely dissolved, adding fresh liquid from time to time as the action ceases. When solution is complete throw in a little common salt dissolved in water, stir vigorously, and allow the precipitated salt to settle. When no more precipitate is formed by the addition of salt water, allow to settle, collect and wash the precipitate on a filter, and fuse in a crucible.

Recovery of tin from tin-plate waste. Treat the waste with dilute chlorine at a temperature above the boiling-point of chloride of tin, so that the latter immediately after its formation is carried away in the form of vapor, since if it remains in the form of fluid in contact with the residues, it gives rise to the formation of chloride of iron, chloride of tin being reduced. The vapors of chloride of tin are precipitated by steam or by contact with moist surfaces in roomy condensing chambers, or are absorbed by chloride of tin solution of medium concentration.

Another method is as follows: Bring the waste into contact with sulphur in a boiling-hot solution of sodium sulphide, whereby the iron is completely freed from tin. The waste thus freed from tin is thoroughly washed and dried, heated to a welding heat in tubes of rolled iron, taken out and hammered into rod iron. The solution of sodium sulphide holding the tin is evaporated, the residue calcined in a reverberatory furnace, and the calcined mass reduced to tin, at a raised heat, by means of a mixture of small coal, charcoal, and calcined soda, or burnt lime.

To separate lead from zinc. Melt the alloy. The specifically heavier lead collects in the lower portion of the crucible while the lighter zinc stands over it and can be poured off.

Recovery of brass from a mixture of iron and brass turnings. This may be effected by means of magnets which attract the iron and steel turnings while the brass remains behind. The same object may be attained in a very simple and economical manner by a melting process. Mix the iron and brass turnings and the slag from brass-casting with limestone, powdered coal and ferric oxide, and melt the mixture, whereby the brass separates from the liquid slag formed, settles on the bottom and is run off into ingot moulds.

INDEX.

ABEL, C. D., alloys patented by, 407–410
Aich's metal, 157, 158
Ajax metal, 301
Alchemy, influence of, upon chemistry, 3, 4
Alfénide, 318
Algiers metal, 231
Alkalies, metals of the, 23, 24
Alkaline earths, metals of, 24
Allevard steel, 395, 396
Alloy, additional increase in the strength of an, by the addition of a third metal, 97–99
change in the properties of an, by remelting and renewed cooling, 67
constitution of an, 5, 6
definition of an, 1
eutectic, 62
for type metal, 357
non-oxidizable, 463
resisting the action of vegetable acids, 319
Sorel's, 191, 192
steels, 388–403
very fusible, 387
which expands on cooling, 467, 468
Alloys, actual constitution of, 8
behavior of, in cooling, 63
casting capacity of, 107–116
color of, 118–121
coloring of, 510–525
condensation in, 70
conductivity for heat and electricity of, 116–118
crystallization of, 93, 94
crystallizing power of, 5
crystals of, 7
separated from, 6
determination of the constituents of, 498–509
development of gases in casting, 113–115
division of, according to specific gravities, 91–93
ductility of, 104–106
earliest historical data in reference to, 2
Alloys, early preparation of, 4
effect of degree of fluidity of, in casting, 112
expansion in, 70
flexibility of, 104–106
formation of, 9, 10
without fusion, 11
fusible, 112
melting points of, 380, 381
general properties of, 62–127
hardness of, 101–104
historical order of, 3
liquation of, 62–69
metals principally employed for, 134
miscellaneous, 463–475
new method of preparing, 463, 464
of copper with other metals, 277–283
mercury and other metals, 445–462
platinum and platinum metals, 433–444
oldest, 2
preparation of, in general, 128–136
protective cover in remelting, 463
remelting of, 132
resembling silver, 420, 421
resistance of, to calcium hydrate, 507
to chemical influences, 121–127
shrinkage of, 115, 116
specific gravity of, 70–93
strength of, 95–101
variation in, 8
very fusible, 380
which can be filed, 281
Alpaka, 307
Aluminium, 17, 24–28
action of, upon brass, 351
alloy for dentists' fillings, 357
type metal, 357
alloying power of, 338
alloys, 338–365
of, with the precious metals, properties of, 339
production of, 338, 339
brass, 351–353

Aluminium brass, tests of, 353
uses of, 352, 353
bronze, 341–351
alloy, 358
brazing of, 359, 360
casting of, 345–349
dilution of a high per cent., to a lower one, 344
forging of, 349
melting point of, 342
preparation of, 342–344
rolling of, 349, 350
soldering of, 360, 361
tests of, 350, 351
-chromium alloy, 358
commercial, analyses of, 27
conductivity of heat of, 25
-copper alloys, 341–351
elongation of, 100
strength of, 96
distribution of, 26
effect of iron on, 27
on metals, 27, 28
electric conductivity of, 25
-gold alloys, 424
solder, 491
increase in the strength of copper by an addition of, 96
-iron alloys, 339, 340
-magnesium alloy, 358, 359
-nickel bronze, 357, 358
-copper alloys, 354–356
preparation of, 26, 27
reduction of, by electrolysis, 26, 27
soldering of, 361–365
specific heat of, 25
-steel, 340, 341
-tin alloy, 359
titaniferous, behavior of, 49
-titanium alloys, 48, 49
Amalgam, definition of an, 1
Amalgams, 445–462
early use of, 3
American anti-friction metal, 301
sleigh bells, alloy for, 474
Anatomical preparations, bismuth amalgam for, 459, 460
Andrews, G. F., alloys recommended by, 357
Anti-friction brasses, alloy for, 300
metal, 301
for hydraulic machinery, 300
metals, table showing compositions of, 302–305
Antimony, 57, 58
alloys of, with gold, 424
-bismuth alloys, specific gravities of, 81 82
Antimony, effect of, on brass, 149, 150
lead, 366
increase in the hardness of lead by alloying with, 103
indication of, 498
-lead alloys, specific gravities of, 82, 83
-tin alloys, specific gravities of, 80, 81
-zinc alloys, crystallization of, 94
Aphtit, 316
Arabs, development of chemistry by the, 3
use of amalgams by the, 3
Argentan, 312–315
solder, 484–486
Argent-Ruolz, 407
Argiroide, 318
Arguzoid, 316
Arnold, Prof, bending tests of vanadium-steel by, 398, 399
Arsenic, 58, 59
alloys of, with gold, 424
determination of, 503, 504
effect of, on bronze, 204
lead, 366
Art-bronze, furnace for melting, 266, 267
melting and casting, 266, 267
moulds for casting, 267
bronzes, 258–267
Ashberry metal, 293
Atomic weight, 21
weights, 135
Austrian Northwest Railroad, white metal bearings used by, 297
Autogenous soldering, 477
Axle-boxes for locomotives and cars, alloy for, 300

BABBITT'S anti-friction metal, 298, 299
Barium, 17
Base metals, 16
alloys of platinum with, 439–441
Bath metal, 192
Bearing metal, Dulevie and Jones', 281
palladium, 442
metals, 294–305
analyses of, 301, 302
cheaper, 280
Bearings, alloys for, 238, 239
composition of white metals for, 298
white metals for, 298
Bell-metal, 226–231
additions of other metals to, 227
melting and casting of, 228, 229

Bell-metal, properties of, 228
metals, composition of some, 229, 230
Bells, disagreeable tone of, 229
early use of, 226
large, weight of some, 227
moulds for casting, 231
Berlin alloys, composition of, 182
Railroad, white metal bearings used by, 296, 297
Berthier's alloy, 308
Biddery metal, 292, 293
Binding wire, 477
Birmingham platinum, 191
Birr Castle, Ireland, telescope mirror at, 244
Bismuth, 57
alloy for cementing glass, 386
alloys, 382–387
for delicate castings, 386
-amalgam, 458, 459
-antimony alloys, 383
-bronze, 315
-copper alloys, 382
effect of, on copper, 140
flexibility of metals, 106
-gold alloys, specific gravities of, 89, 90
group, 57, 58
indication of, 498
-iron alloys, 383
-lead alloys, 383, 387
specific gravities of, 88, 89
-tin alloys, fusing temperatures of, 386
-silver alloys, specific gravities of, 88
solder, 480
-tin alloys, 382, 383, 387
-lead alloys, 384
Black bronze, 472
Blanching, 415, 416
Block tin, 46
Bobierre's metal, 157
Borax, 130
Bourbouze's aluminium solder, 362
Brass, action of aluminium upon, 351
bronze substitute for, 240
bronzing of, 521, 522
liquids for, 516
cast, 151–153
casting of, 172–179
change in the molecular structure of, 147
cleaning or pickling of, 179–181
coloring of, 520, 521
Brass, composition of, 144
crystalline structure of, 145
dull, lustreless surface on, 180
early manufacture of, 142
effect of an addition of tin on, 148
for sheet and wire, composition of, 151
furnaces, 165–170
for the fusion of, directly upon the hearth, 170, 171
gold color on, 518, 519
improved hard solder for, 484
ingots, casting of, 173, 174
introduction of the manufacture of, 143, 144
iridescent coatings on, 518
Japanese, 151
lustrous gray or black on, 517, 518
malleable, 155, 156
manufacture of, 163–179
by direct fusion of the metals, 165–172
with the use of zinc ores, 163–165
melting point of, 147, 148
moulds for casting, 173, 174
pickles for, 179, 180
plate, casting of, 174–179
properties, manufacture, and uses of, 143–181
recovery of, from a mixture of iron and brass turnings, 532
sheet, 149–151
production of, 176, 177
silver color on, 519
solder, 487
solder, 480–484
preparation of, 481–483
soldering of, 494
strength of, 147
superiority of German silver to, 309
table showing the properties of, as affected by its composition, 149
testing of, 504, 505
tough, for tubes, 153, 154
use of old copper in the manufacture of, 148
very ductile, 147
Brazing aluminium bronze, 359, 360
Bristol brass, 155
Britannia metal, 287–292
composition of several varieties of, 288, 289
preparation of, 289, 290

Britannia metal, properties of, 287, 288
shaping of, 290, 291
testing of, 505
Brocade, 189, 190
Bronze age, 201
basin, Turkish, 265
behavior of, towards the atmosphere, 212
black, 472
castings, defective, 241
change in the molecular structure of, 206, 207
Chinese, 203
color, brown, 522
green, 522
definition of, 201, 202
deoxidized, 162
derivation of the term, 201
different kinds of, 216–219
difficulty in obtaining perfect castings of, 208, 209
ductility of, 205, 206
early use of, 3, 141, 142
effect of admixtures on, 203, 204
eutectic alloy of, 212
for articles exposed to shocks and very great friction, 239
ship-sheathing, 235, 236
small castings, 234
telephone lines, 253, 254
valve balls, 239, 240
formation of blisters and pores in, 241
fused, effect of cooling on, 204, 205
furnaces for melting, 214–216
imitation, 183
in general, 201–212
iridescent coatings on, 518
lustrous gray or black on, 517, 518
melting and casting, 212–216
moulds for casting, 241
poling of, 240, 241
powders, 188–190
preparation of large quantities of, 213, 214
resisting acids, 467
action of the air, 240
securing the greatest strength of, 207
-sheet, crystallization of, 146
statuary, alloys of different colors suitable for, 262
table of density and composition of, 207, 208
testing of, 505, 506
to be gilded, 235
upon French bronze figures, 514–516
Bronze, use of, as a substitute for iron, 237
variations in the color of, 205
weapon, antique, 265
Bronzes, Chinese, 263, 264
deterioration of, by remelting, 240, 241
Fontainemoreau's, 192, 193
for various purposes, 231–244
Japanese, 265
melting points of, 208
prehistoric, 216–219
properties of, 202, 203
strength and hardness of, 206
tendency towards liquation of, 211
Bronzing liquids, 516, 517
Brunswick, Germany, telescope mirror at, 244
Buttons, alloys for, 191, 192

CADMAN, A. W., Babbitt metal patented by, 299
Cadmium, 40–42
alloying power of, 41
alloys, 378–381
constancy of, 381
-amalgam, 41, 42, 455, 456
-bismuth alloys, specific gravities of, 87
determination of, 503
-lead alloys, specific gravities of, 87, 88
properties of, 41
pure metallic, preparation of, 40, 41
Calcium, 17
Calico-printing rollers, alloys for, 469–471
Calin, 463
Camelia metal, 301
Cannon, early use of bronze for casting, 219
old, use of, in casting ordnance, 224
Carats and grains, conversion of, into thousandths, 428
Car-axle-boxes, alloy for, 300
-box metal, 301
-brasses, metal for lining, 301
Carbon, 60, 61
absorption of, by iron, 11
-bronze, 301
effect of, on iron, 389
Carty, specific gravities of bismuth-lead alloys according to, 88, 89
tin-bismuth alloys according to, 83, 84

Cassiterite, 45
Cast-brass, 151–153
fine, 153
French, for fine castings, 154
ordinary, 152, 153
-iron, 61
silver solder for, 489
Casting aluminium bronze, 345–349
brass, 172–179
capacity, 107–116
development of gases in, 113–115
plate brass, 174–179
shot, 372–376
small articles, alloy for, 474
Castings, delicate, bismuth alloys for, 386
small, bronze for, 234
Celestite, 17
Charpy's experiments with zinc-copper alloys, 97
investigations of copper-zinc alloys, 143
Chemical combination, definition of a, 21
formulas, 22
influences, resistance of alloys to, 121–127
Chemistry, development of, by the Arabs, 3
influence of alchemy upon, 3, 4
preparation of alloys, a branch of, 4
China silver, 307
Chinese bronze, 203
bronzes, 263, 264
metal mirror, 244
tam-tams or gongs, 230, 231
Chisels, alloys for, 465
Christophle metal, 307
Chrome steel, 391–393
Chromium, 37
experiments showing influence of vanadium on, 403
indication of, 501
Chrysochalk, 183
Chrysorin, 154, 183
Church bells, introduction of, 226, 227
Cinnabar, 53
Clark's patent alloy, 421
Cleaning brass, 179–181
Cliché metal, 380, 383, 384
Clock-bells, small, alloy for, 230
Cobalt, 34, 35
alloying power of, 35
bronze, 282
indication of, 501
naturally occurring compounds of, 34
Coin bronze, 232, 233
Coinage, silver-zinc alloys for, 406
Coins, gold, fineness of, 429
manganese brass for, 281
silver, composition of, 413, 414
Swiss fractional, 411
use of nickel for, 37
Cologne, weight of large bell in, 227
Color of alloys, 118–121
Coloring of alloys, 510-525
Colors, temperatures corresponding to different, 14
Common salt solution, formation of ice in a, 62, 63
Compensation balances, alloy for, 471, 472
Conductivity for heat and electricity, 116–118
Cooper's mirror metal, 441
pen metal, 441
Copper, 52, 53
alloying power of, 53
-alloys, 137, 200
most important, 140
of, with base metals, 141, 142
other metals, 277-233
-amalgam, 450, 451
and much zinc, alloys of, 280
-antimony alloys, 282, 283
melting temperatures of, 111
-arsenic alloys, 277
black on, 514
blue-black on, 514
-gray on, 514
bronzing liquids for, 517
of, 514, 521, 522
brown color on, 513
browning liquid for, 520
-cobalt alloys, 281, 282
commercial, sources of, 140
conductivity of, 117
early alloys of, 2
effect of foreign bodies on, 137–140
silicon on, 251
flexibility of, 105
formation of cuprous oxide in, 8
-gold alloys, 140, 141
specific gravities of, 78
increase in strength of, 96
of, by an addition of aluminium, 96
of, by an addition of zinc, 97

Copper, indication of, 499
-iron alloys, 278, 466
Japanese, 417
-lead alloys, 277, 278
liquation of, 69
-magnesium alloys, 282
matt-black on, 514
melting point of, 108
-nickel-silver alloys, 322, 323
old, use of, in the manufacture of brass, 148
recovery of, 531
red-brown on, 513, 522
separation of silver from, 531
-silver alloys, 141
resistance of, to chemical influences, 125
specific gravities of, 77, 78
wear of, by abrasion, 103
soldering of, 494
-steel, 279, 280
tensile strength of, 275, 276
test for the quality of, 150, 151
-tin alloys, 201, 276
crystallization of, 93
determinations of the specific gravities of, 71–76
hardness of, 102
liquation of, 68
resistance of to acids and salts, 123
strength of, 99, 100
table of mechanical and physical properties of, 267–273
-nickel alloys, with or without zinc, 322
-tungsten alloys, 281
varying intensity of coloration produced by, 119, 120
-zinc alloys, 142–200
behavior of, 144, 145
crystallization of, 93, 94
influence of sea-water upon, 123, 124
liquation of, 69
melting temperatures of, 109
physical properties of, 145–149
resistance of, to acids and salts, 123
specific gravities of, 76, 77
Copper-zinc alloys, table of the properties of, 193–197
-nickel alloys, composition of, 320, 321
-iron alloys, composition of, 321, 322
-lead alloys, composition of, 321
-tin alloys, influence of sea-water upon, 123, 124
Cornish bronze, 301
Crucible furnace, revolving, 169, 170
Crucibles, 128, 129
for melting brass, 166, 167
furnaces for, 165–170
Crystallization, 93, 94
Cuivre-fumé, 514
Cupro-manganese, preparation of, 254–256
properties of, 256
Cuprous oxide, effect of, on copper, 138
formation of, in copper, 8
Cutting tools, hard alloys for, 333
Cymbals, early use of, 226

DAMASCUS bronze, 301
D'Arcet's fusible alloys, 385
gilding metals, 155
Dead-head, 221
Dechenite, 43
Delalot's alloy, 420
Delta metal, 159–161
strength of, 98
Dentists' fillings, aluminium alloy for, 357
Deoxidized bronze, 162
Dewrance's patent bearing for locomotives, 300
Dutch leaf, 186–188
Dienett's German silver, 317
Drilling tools, hard alloys for, 333
Drills, alloys for, 465
Dronier's malleable bronze, 452
Ductility, 104–106
Dudley, C. B., investigations of bearing metals by, 301, 302
Dulevie and Jones' bearing metal, 281
Durano metal, 161
Dutch gold, 186–188

EGYPTIAN metal mirror, 244
Electric furnace, Moisson and Violle's, 47, 48
of Deutsche Gold und Silberscheideanstalt, 50, 51

Electricity and heat, conductivity of alloys for, 116–118
Elements, classification of, 12
combination of, 135
groups of, 12
names, symbols and atomic weights of, 21, 22
Enameled work, solders for, 490
England, introduction of the manufacture of brass in, 144
silver-copper alloys employed in, for manufacturing purposes, 414, 415
English metal, 293, 294
process of manufacturing German silver, 327–329
sterro-metal, 158, 159
type metals, 368
white metal, 300
ordinary, 192
Erfurt, weight of large bell in, 227
Erhart's type metal, 369
Erythrine, 34
Eutectic alloy, 62
lead-tin alloy, 66
silver copper alloy, 65, 66
Evans's metallic cement, 456
Ex. B. metal, 301

FAHLUN brilliants, 285
Fat, use of, in melting metals, 130
Fenton's alloy for axle-boxes for locomotives and cars, 300
Ferro-chrome, preparation of, 391, 392
-cobalt, malleable, 466, 467
-German silver, 316
-manganese, 390, 391
-nickel, 466, 467
production of, 335, 336
-tungsten, 393, 394
Fire-gilding, 448–450
early knowledge of, 3
gold amalgam for, 447
Fireworks, magnesium alloys for, 29, 30
Fleitman, Dr., process of, for refining and toughening nickel, 36
Flexibility, 104–106
Fluidity, 112
Flutes, alloy for keys of, 370
Flux for hard soldering, 489, 493, 494
Fontainemoreau's bronzes, 192, 193
Forging aluminium bronze, 349
Foundry pig, 389
French bronze figures, bronze upon, 514–516
ordnance, analyses of, 68
oröide, 184, 185
silver solder, 487
type metals, 368
Frishmuth's aluminium solder, 362
Furnace for melting art-bronze, 266, 267
platinum, 433, 434
reverberatory, for wood-firing, 177
used by gold-ware manufacturers, 426, 427
Furnaces, brass, 165–170
for heating German-silver sheet, 329–332
melting bronze, 214–216
gun-metal 222–224
Fusible alloys, 112
amalgams of the, 456, 457
D'Arcet's, 385
melting points of, 380, 381

GALLIUM, 42
Gases, development of, 113–115
origin of, 114
Gedge's alloy for ship-sheathing, 158, 159
Geitner, Dr., invention of argentan by, 307
General properties of alloys, 62–127
German admiralty specifications for Babbitt metal, 299
process of manufacturing German silver, 325–327
silver, 312–315
additions to, 310, 311
alloy resembling, 463
analyses of, 313, 314
foil, 329
invention of, 307
manufacture of, 324–332
mechanical manipulation of, 312
sheet, manufacture of, 329–332
substitutes for, 315–319
superiority of, to brass, 309
testing of, 506
Germany, introduction of the manufacture of brass in, 144
Gilding metals, D'Arcet's, 155
spurious, 455
Glass, 130
bismuth alloy for cementing, 386
globes, amalgams for silvering, 459
pressed, alloy for moulds for, 463
Godfrey's silver-zinc alloys, 405, 406
Gold, 55, 56
alloys, 422–432
colors of, 429
melting temperatures of, 109
preparation of, 424–427
by the galvanic process, 432
proportions of various metals incorporated in, 430, 431
standards of, 427

Gold alloys, use of, 428–432
which can be legally used in various countries, 430
-aluminium alloys, 424
properties of, 339
solder, 363
amalgam, 446–448
containing silver, 447, 448
for fire gilding, 447
native, 448
behavior of lead towards, 423
bronze, 234, 235
coins, composition of, 141
fineness of, 429
colored, 431
coloring finished articles of, 432
power of, 121
-copper, 183
alloys, 423
flexibility of, 106
liquation of, 69
early alloys of, 2
granulated, 427
group, 55–57
increase in the strength of, by alloying, 97
-iron alloys, 423
-like alloy, 472, 473
-palladium alloys, 424
recovery of, by the wet process, 528
from auriferous fluids, 527
cyanide solutions, 527, 528
wash-water, 526
scrap, remelting of, 427
separation of silver from, 528, 529
-silver alloys, 423
crystallization of, 94
liquation of, 69
resistance of, to chemical influences, 125
solders, 489–491
-tin alloys, crystallizations of, 94
-ware manufacturers, furnace used by, 426, 427
testing of, 506, 507
waste recovery of, 526–528
wires, strength of, 98
Gongs, Chinese, 230, 231
Graham's bronzing liquids, 516, 517
Grain tin, 46
Graney bronze, 301
Granite moulds for plate-brass, 175, 176
Granulated gold, 427
Graphite, 60
-bearing metal, 301
Gray gold, 423
Gray pig iron, 389
Greek coin-bronze, 233
Greeks, knowledge of the art of mixing metals by the, 2
use of amalgams by the, 3
Green gold, 423
Greenockite, 40
Guettier's button metals, 192
Gun-barrels, browning of, 523, 524
-metal, 219-226
effect of casting temperature on, 224, 225
furnaces for melting, 222–224
properties of good, 220, 221

HALF-WHITE solder, 481
-yellow solder, 481
Hamilton's metal, 154
Hampe's researches on the effect of admixtures on copper, 139, 140
Hard silver solder, 487
soldering fluid, 493
flux for, 489
solders, 480–486
Hardness, 101–104
determination of the degree of, 102
Harrington bronze, 301
Heat and electricity, conductivity of alloys for, 116–118
development of, in alloying metals, 10, 11
Heavy metals, 16, 30, 59
groups of, 18, 19
Hélouise's investigations of the effect of vanadium on steel, 397, 398
Henniger Bros., invention of Neusilber by, 307
Holland, John, process of, for making phosphor-iridium, 443
Holzmann, specific gravities of antimony-bismuth alloys according to, 81, 82
bismuth-gold alloys according to, 89, 90
bismuth-silver alloys according to, 88
cadmium-lead alloys according to, 87, 88
tin-gold alloys according to, 86
tin-mercury alloys according to, 90, 91
tin-silver alloys according to, 84, 85

Homestead, Pa., preparation of nickel-steel at, 336
Höper's phosphor-bronze, 250
Hoyle's patent alloy for pivot bearings, 300
Hydraulic machinery, anti-friction metal for, 300

ILLUMINATING purposes, pyrophorous alloys for, 473
Imitation bronze, 183
Indium, 42
-gallium alloys, 464, 465
Iridium-osmium alloy, 442
-steel, 442
Iron, 30–33
absorption of carbon by, 11
nickel by, 11
addition of, to German silver, 310, 311
affinity of, for lead, 366
alloying power of, 32
alloys, 388–403
technical importance of, 33
amalgam, 457, 458
and brass turnings, recovery of brass from a mixture of, 532
blue on, 524
brown-black coating with bronze luster on, 524
chemically pure, preparation of, 31, 32
cold-short, 20
commercial, 1, 388
constitution of, 31
derivation of substances which combine with, 388
determination of, 509
effect of, on aluminium, 27
on bronze, 204
on copper, 138
phosphorus on, 61
group, 30–38
hot-short, 20
increase in the hardness of, 103, 104
influence of carbon on, 60, 61
lustrous black on, 524
-manganese alloys, crystallization of, 94
most important constituent of, 389
native, 30, 31
pure, 20
red-short, 20
reduction in the melting temperature of, 108
silvery appearance with high luster on, 525
solution of, in zinc, 33
Iron-tin alloys, crystallization of, 94
use of bronze as a substitute for, 237
varieties of, 389
with chromium, tungsten, molybdenum, alloys of, 465, 466

JAPANESE brass, 151
bronzes, 265
remarkable series of alloys of, 416-419
Jewelers, proportions of various metals incorporated in gold alloys used by, 430, 431
Jewelry, soldering of, 496, 497
Joujou gold, 429

KAPFENBERG ferro-chrome, 392
Kalischer, S., researches of, in regard to metals becoming crystalline, 145–147
Karmarsch, brass solders, according to, 484
determinations of specific gravities of copper-silver alloys by, 77, 78
investigations of Britannia metal by, 289
Kerl on the effect of antimony on brass, 150
Keys of flutes, alloy for, 370
Kilogrammes, alloy for, 435
King crucible, 167
Kingston's metal, 300
Kuromi, 417, 418

LACQUERS, table of, 510, 511
Lancon's aluminium solder, 362, 363
Langley, J. W., on aluminium-steel, 340, 341
Lead, 51, 52
addition of, to German silver, 314, 315
alloying power of, 52
alloys, 366–377
-amalgams, specific gravities of, 91
behavior of, towards gold, 423
detection of, in tin, 508
determination of, 502
effect of, on bronze, 203
copper, 137, 138
-foil, to distinguish tin-foil from, 508
-gold alloys, specific gravities of, 79, 80
group, 51, 52
increase in the hardness of, by alloying with antimony, 103
indication of, 498

Lead-iron alloys, 376, 377
melting point of, 107
-mercury alloys, specific gravities of, 91
rolled, crystalline structure of, 146
separation of, from zinc, 532
-silver alloys, crystallization of, 94
liquation of, 69
tempered, 475
-tin alloys, action of acids and salt solutions upon, 125–127
hardness of, 103
melting temperatures of, 107, 108
eutectic alloy, 66
Lead vanadate, 400
Lechesne, 356, 357
Ledebur, type metal according to, 369
Lichtenberg's metal, 385
Light metals, 16, 17
Lipowitz's alloy, 378, 379
metal, amalgam of, 456, 457
Liquation, 62–69
definition of, 66
effect of, in working metals, 66, 67
Lithium, 17, 24
Loam moulds for plate-brass, 175
Locomotive axle-boxes, alloy for, 300
Locomotives, Dewrance's patent bearing for, 300
Long, specific gravities of antimony-tin alloys, according to, 80, 81
of tin-lead alloys, according to, 85, 86
Looking glasses, amalgam for, 452, 453
Lutecine, 468
Lyons gold, 182

MACHINE-BRONZE, 236–240
composition of, 237, 238
Macht's yellow metal, 157
Mackenzie's amalgam, 462
Magic mirrors, 244
spoon, 387
Magnesium, 17, 28–30
alloys for fireworks, 29, 30
preparation of, 29
amalgamation of, with mercury, 29
determination of, 500, 501
-potassium alloys, 29
properties of, 28, 29
-sodium alloys, 29
Magnolia metal, 301
Maillechort, invention of, 307
Malleable brass, 155, 156
iron, 389
Manganese, 33, 34
alloying power of, 34
brass, 281
-bronze, 254–258, 301
preparation of, 256, 257
effect of, on iron, 390
German silver, 316
steel, 390, 391
testing for, 501, 502
Manganin, 317
Manilla gold, 186
Mannheim gold, 183
Marbeau's nickel-spiegel, 335
Marbled alloy, 418–420
Marcus Aurelius, statue of, 3
Marlie's non-oxidizable alloy, 474
Marsh's apparatus, 503, 504
Marshasila, 38
Martino's hard alloys for drilling and cutting tools, 333
platinoid, 316, 317
Matthiessen, A., investigation of the conducting power for electricity of metals by, 116, 117
specific gravities of antimony-lead alloys according to, 82, 83
cadmium-bismuth alloys according to, 87
lead-gold alloys according to, 79, 80
silver-lead alloys according to, 80
silver-gold alloys according to, 79
tin-cadmium alloys according to, 83
Medal bronze, 232, 233
Melting and casting art-bronze, 266, 267
bell-metal, 228, 229
bronze, 212–216
in a reverberatory furnace, 129, 130
temperature, effect of, in casting, 107–112
utensils, 128
Mercury, 53, 54

Mercury, alloying or amalgamating power of, 54
alloys of, and other metals, 445–462
amalgamation of magnesium with, 29
early knowledge of, 3
indication of, 499
testing of, 508
Metal castings, alloy for filling out defective places in, 384
changes in the properties of a, by alloying, 1
definition of a, 13
for lining car brasses, 301
Metallic cement, Evans's, 456
Vienna, 451, 452
pencils, 460
Metalline, 357
Metalloids, 8, 9, 12
Metals, 12
addition of, to bell-metal, 227
affinity of, for oxygen, 15, 16
alloying larger quantities of one, with smaller quantities of another, 133, 134
alloying power of, 9
base, alloys of copper with, 141, 142
bases, 16
bismuth group of, 57, 58
chemical relations of the, 15–22
combination of, with non-metals, 135, 136
sulphur, 59, 60
common characteristics of, 15
development of gases in casting, 113–115
heat in alloying, 10, 11
early knowledge of mixing, 2
effect of aluminium on, 27, 28
bismuth on the flexibility of, 106
degree of fluidity of, in casting, 112
different, on bronze, 203, 204
liquation on working, 66, 67
phosphorus on, 61
gold group of, 55–57
groups of, 17
heavy, 16, 30–59
groups of, 18, 19
increase in the limit of elasticity of, by alloying, 99
iron group of, 30–38
Metals, law regarding the influences exerted upon the strength of, by alloying, 95
lead group of, 51, 52
light, 16, 17
liquid, solidification of, 67, 68
most important, determination of impurities of, 498–509
noble, 16
preparation of alloys from, 131
of the alkalies, 17, 23, 24
alkaline earths, 17, 24
earths, 17, 18, 24, 30
physical and chemical relations of the, 12–22
relations of the, 13–15
principally employed for alloys, 134
properties of, 13, 14
resistance of, to calcium hydrate, 507
scale of the coloring power of, 119
shrinkage of, 115, 116
silver group of, 52–55
special properties of, 23–61
strength of, 95
tendency of, to become crystalline, 145–147
tin group of, 45–51
tungsten group of, 42–45
use of fat, in melting, 130
white, 294–305
zinc group of, 38–42
Meteorites, 31
Meter rules, alloy for, 435
Mierzinski's solder for aluminium bronze, 360
Milan, weight of large bell in, 227
Minargent, 420
Minofor metal, 293
Mira metal, 283
Mirror, Chinese, 244
composition of a, 242
Egyptian, 244
-metal, Cooper's, 441
Roman, 244
Mirrors, amalgam for, 452, 453
concave, alloy for, 243
magic, 244
Mitis castings, 339
Moissan and Violle's electric furnace, 47, 48
Moku-me, 418–420
Molybdenum, 43
Mosaic gold, 154
Moscow, Russia, weight of large bell in, 227
Moulds for Britannia metal, 290
casting art-bronze, 267
articles of brass, 174

Moulds for casting bells, 231
bronze, 241
ingots of brass, 173, 174
pressed glass, alloy for, 463
Mourey's aluminium solders, 361, 362
Mouset's silver alloy, 411
Mudge, specula made by, 242
Muffle furnace for heating German silver sheet, 329–332
Muntz metal, 156, 157
Mushet steel, 395, 396
Music, composition of plates for engraving, 369
Musiv silver, 454

NEWTON'S metal, 384
Nickel, 35–37
absorption of, by iron, 11
alloying power of, 36, 37
alloys, 306–337
analyses of, 324
composition of, 319–323
properties of, 311
-aluminium alloy, 333
amalgam, 462
arsenic in, 309, 310
-bronze, 315
coloring power of, 120, 121
-copper alloys, 307–309
-zinc alloys, 309–322
effect of, on bronze, 204
indication of, 501
ores, reduction of, 310
refining and toughening of, 36
purification of, 408
source of, 309
-speiss, treatment of, 408, 409
-spiegel, Marbeau's, 335
-steel, 333–337
alloys, 37
conductivity of, 337
tests of, 337
testing of, 508
-tin alloy, 332, 333
use of, for coins, 37
waste, utilization of, 530
Noble metals, preparation of alloys from, 131
Non-metals, 8, 9, 12, 16
combination of, with metals, 135, 136
Non-oxidizable alloy, 463, 474

OLMÜTZ, weight of large bell in, 227
Onion's fusible alloy, 385
Ordnance-bronze, 219–226
composition of, 226
cooling of, 225
Ordnance-bronze, effect of casting temperature on, 224, 225
French, analyses of, 68
or gun metal, 219–226
use of old cannon in casting, 224
Orëide, French, 184, 185
Ormolu, 234
Oxygen, affinity of metals for, 15, 16
effect of, on bronze, 209

PACKFONG, 306
foil, 329
Pale gold, 423
Palladium alloys, 441, 442
bearing metal, 442
Paris metal, 468
weight of large bell in, 227
Partinium, 358
Patina, 124, 260, 261
coating, similar to, 511, 512
Patterns, small, alloys for, 468, 469
Pattinson's desilverizing process, 6
Pen-metal, Cooper's, 441
Pennsylvania Railroad Co., Ex-B metal of, 301
Pforzheim gold, 430
Pholin's silver-like alloy, 460
Phosphor-aluminium bronze, 250, 251
-bronze, 61, 244–251
analyses of, 249
content of phosphorus in, 248
grades of, 249
preparation of, 246
properties of correctly-prepared, 247
results of physical tests of, 247, 248
uses of, 248
wire, 247
-copper, 246
-iridium, 443, 444
-lead bronzes, 250
-tin, 246, 247
Phosphorus, 61
content of, in phosphor-bronze, 248
effect of, on bronze, 210
on copper, 139
Physical and chemical relations of the metals, 12–22
Piat's revolving crucible furnace, 169, 170
Pickling brass, 179–181
solution, 417
Pig iron, 389
Pinchbeck, 184
Pirsch's German silver, 318
-Baudoin's alloy, 421
Pivot bearings, alloy for, 300

Platina, 186
Platine au titre, 437
Platinoid, 316, 317
Platinor, 437, 438
Platinum, 56, 57
alloys of, with the base metals, 439–441
preparation of, 434
aluminium solder, 363
amalgam, 462
and platinum metals, alloys of, 433–444
-bronze, 438
-copper alloys, 439–441
furnace, 433–434
-gold alloys, 436
melting points of, 436
-silver alloys, 437
indication of, 498
iridium alloys, 434, 435
-iron alloys, 439
-lead, 191
-palladium alloys, 435
properties of, 433
-silver alloys, 437
Plumbago, 60
Plumbers' sealed solder, 479
Potassium, 17, 23
-amalgam, 461, 462
-magnesium alloys, 29
Potin gris, 152, 153
Potin jaune, 152, 153
Prechtl brass solders, 484
Preparation of alloys in general, 128–136
Prince's metal, 155
Pyrometric measurements, use of platinum-gold alloys for, 436
Pyrophorous alloys for illuminating purposes, 473

QUICKSILVER, 53, 54

REFLECTORS, aluminium-magnesium alloy for, 359
Reverberatory furnace for melting bronze, 214
for wood firing, 177
melting in a, 129, 130
Revolving crucible furnace, 169, 170
Rheostats, alloy for, 257, 258
Rhodium-steel, 442
Richards' aluminium solder, 364, 365
bronze, 353
Riche, determinations of specific gravities of copper-zinc alloys, by, 76, 77
Riche and Thurston, determinations of the specific gravities of copper-tin alloys, by, 71–76
Riley, James, on nickel-steel alloys, 37, 336
Roberts, determination of specific gravities of copper-gold alloys by, 78
Robertson's alloy for filling teeth, 474
Rolling aluminium-bronze, examples of, 349, 350
Roman coin-bronze, 233
Roman metal mirror, 244
Rome, weight of large bell in, 227
Ronia metal, 155
Rose's alloys, 384
metal, 112
Rosëin, 333
Ross, composition of speculum metal according to, 242, 243
telescope, composition of the mirror of, 243
Rubbers of electrical machines, amalgam for coating, 453, 454
Ruolz alloys, 322, 323

SAFETY-PLATES for steam boilers, 384
Salgee anti-friction metal, 301
Salt, common, solutions, 6, 7
Sauer's aluminium solder, 363, 364
Scheelite, 43
Schlosser's solder for aluminium bronze, 360, 361
Schneider, M. Henry, patent of, for copper-steel, 279
patents of, for manufacture of alloys of cast-iron and nickel, steel and nickel, 333–335
Scrap-gold, remelting of, 427
Shaku-do, 416
Sheet brass, 149–151
crystalline, structure of, 146
production of, 176, 177
-copper, crystalline structure of, 146
-iron, crystalline structure of, 146
-tombac, crystalline structure of, 146
Sheffield Britannia metal, 289
Shibu-ichi, 416, 417
Ship-sheathing, bronze for, 235, 236
Gedge's alloy for, 158, 159
Shot, casting of, 372–376
formation of by centrifugal power, 373
large, manufacture of, 376
-metal, 370–376

Shot, mixture of metals for, 370
preparation of, 371
sorting of, 375, 376
-towers, 372
-wells. 372
Shrinkage, 115. 116
Sideraphite, 472
Sign-plates, alloy for, 474, 475
Silicon-bronze, 251–254
properties of, 251
telegraph wire, 251–254
effect of, on copper, 138, 139, 251
iron, 389
Silver, 54, 55
addition of, to German silver, 311
alloy resembling, 463
alloying power of, 55
alloys, 404–421
melting temperatures of, 109
resembling, 420, 421
solder for, 487
aluminium alloys, 404, 405
properties of, 339
amalgam, 448
-arsenic alloys, 411
bell-metal, 231
bronze, 333
coins, composition of, 413, 414
-copper alloy, magnified surfaces of a, 64, 65
alloys, 412, 416
flexibility of, 106
liquation of, 69
-cadmium alloys, 411, 412
eutectic alloy, 65. 66
-nickel alloys, 406. 407
-zinc alloys, 410, 411
crystals, separation of, from a melted silver-copper alloy, 63
early alloys of, 2
flexibility of, 105, 106
-gold alloys, specific gravities of, 79
group, 52–55
increase in the strength of, by alloying, 97
indication of, 499
-lead alloys, specific gravities of, 80
-like alloy, 316, 460
melting point of, 108
-mercury alloys, crystallization of, 94
oxidizing of, 525
prize offered for the invention of a substitute for, 306, 307
recovery of, from cyanide solutions, 529, 530
separation of, from copper, 531
Silver, separation of, from gold, 528, 529
solder for cast-iron, 489
for steel, 489
French, 487
hard, 487
ordinary hard, 487
soft, 487
solders for special work, 488, 489
-waste, recovery of, 528–530
-zinc alloys, 405, 406
Silverine, 307
Silvering, alloy for, 473, 474
Similor, 183
Singer's amalgam for coating rubbers of electrical machines, 454
Sleigh bells, alloy for, 230
American, alloy for, 474
Smaltine. 34
Smith, David, invention of, for manufacturing drop-shot, 373–375
Smith, J. Kent, on vanadium steel, 399, 400
tests by, of steel with and without vanadium, 398
Sodium, 17, 23
alloys of magnesium with, 29
amalgam, 460, 461
Soft silver solder, 487
solders, 478–480
coloring of, 521
Solbisky's nickel-aluminium alloys, 333
Solder for manganese-brass, 281
soft, preparation of, 479, 480
Soldering aluminium, 361–365
bronze, 360, 361
autogenous, 477
fat, 493
fluids, 491–497
jewelry, 496, 497
pan, 496, 497
processes, conditions to be observed in, 476, 477
treatment of solders in, 491–497
Solders and soldering, 476–497
constituents of, 476
containing precious metals, 486–491
for aluminium, 361–365
enameled work, 490
hard, 480–486
in general, 476–478
soft, 478–480
coloring of, 521
composition and melting points of, 478, 479
testing of, 508
treatment of, in soldering, 491–497
varieties of, 476

Solutions, change in the physical properties of, 6
Sorel's alloy, 191, 192
Special properties of the metals, 23–61
Specific gravity of alloys, 70-93
rule for calculating the, 71
Speculum metal, 242–244
actual, composition of, 242
various compositions used for, 243
Speiss, 35
Spelter, 39
Spence's metal, 468
Sperry, E. S., analyses of nickel alloys by, 324
investigations of, on the influence of antimony on brass, 149, 150
Spoons, alloy for, 463
Statuary bronze, alloys of different colors suitable for, 262
Statues, best bronze for, 262
celebrated, composition of, 262, 263
mixture of metals for casting, 259, 260
Statuettes, small, manufacture of, 457
Steam boilers, safety plates for, 384
Steel, 20, 61, 389
articles, baths used in tempering and heating, 286
-bronze, 225, 226
comparative effect of chromium and vanadium on, 399
composition, 465
effect of chromium in, 392, 393
Hélouise's investigations of the effect of vanadium on, 397, 398
results obtained by the addition of vanadium to, 401
silver solder for, 489
tools, tempering of, 387
with and without vanadium, tests of, 398
Sterling metal, 152, 153
Sterro-metal, 158, 159
Stopcocks, alloy for, 300
Stream-tin, 45
Strength of alloys, 95–101
tensile, 95
Strontianite, 17
Strontium, 17
Suhl white copper, 306
Sullage piece, 221, 222
Sulphur, 59, 60
effect of, on copper, 138, 139
Sulphuretted hydrogen, apparatus for preparing, 499, 500
Sun-bronze, 357
Swiss coins, composition of, 311
Swiss fractional coins, 411
Symbols, formation of the, 21

TABLE bells, alloy for, 230
for conversion of carats and grains into thousandths, 428
of analyses of German silver, 313, 314
nickel alloys, 324
of names, symbols and atomic weights of the elements, 21, 22
showing comparative effect of chromium and vanadium on steel, 399
composition and melting-points of soft-solders, 478, 479
and melting-points of solders, 495
of alloys for bearings, 238, 239
of alloys for calico printing rollers, 476, 477
of alloys of different colors suitable for statuary bronze, 262
of ancient bronzes, 219
of anti-friction metals, 302–305
of Britannia metal, 289
of bell metals, 229, 230
of brass for sheet and wire, 151
of brass solders, 483
of cast-brass, 152
of celebrated statues, 262, 263
of gold alloys most frequently used, with their specific colors, 431
of gold solders, 490
of machine bronze, 238
of nickel alloys, 319–323
of ordnance-bronze, 226
of silver coins of various nations, 414
of silver-copper alloys employed in England for manufacturing purposes, 414, 415
of tombac, 182
of white metals for bearings, 298
density and composition of bronze, 207, 208
fusing temperatures of bismuth-lead-tin alloys, 386
influence of vanadium on chrome, 403

Table showing mechanical and physical properties of copper-tin alloys, 267–273
melting points of tin-lead alloys, 286
properties of brass as affected by its composition, 149
of copper-zinc alloys, 193–197
proportions of various metals incorporated in gold alloys used by jewelers, 430, 431
results obtained by the addition of vanadium to steel, 401
Talmi gold, 185, 186
Tambago, 181
Tam-tams, Chinese, 230, 231
Taylor and White special "quick speed" cutting steels, 396
Teeth, amalgam for filling, 456
Robertson's alloy for filling, 474
Telegraph wire, silicon bronze, 251–254
Telephone wire, silicon bronze, 251–254
Telescope mirror at Birr Castle, Ireland, 244
Temperatures corresponding to different colors, 14
Tempered lead, 475
Tetmajer, experiments of, with aluminium-copper alloys, 96
Thallium, 52
Thowless' aluminium solder, 363
Thurston, Prof. R. H., investigation by, of the strength of copper-tin alloys, 99, 100
Tiers-argent, 405
Tin, 45, 46
addition of, to German silver, 311
alloying power of, 46
alloys, 284–305
warm sepia-brown on, 525
amalgam, 452
-amalgams, specific gravities of, 90, 91
-bismuth alloys, specific gravities of, 83, 84
bronze-like patina on, 525
-cadmium alloys, specific gravities of, 83
commercial, analyses of, 45
detection of lead in, 508
effect of, on brass, 148
lead, 366
-foil to distinguish from lead-foil, 508
-gold alloys, specific gravities of, 86
Tin group, 45–51
-lead alloys, 284–286
densities of, 284
melting points of, 285, 286
specific gravities of, 85, 86
melting point of, 107
-mercury alloys, specific gravities of, 90, 91
properties of, 45, 46
recovery of, from tin-plate waste, 531, 532
-silver alloys, specific gravities of, 84, 85
-spots, 243
stains, 68
-stone, 45
testing of, 508
unmanufactured, varieties of, 46
use of, as a solder, 478
warm sepia-brown tone on, 525
Tinning, amalgam for, 454
Tissier's metal, 186
Titaniferous aluminium, behavior of, 49
Titanium, 46–51
-bronze, 48
metallic, preparation of, 47
Tobin bronze, 161, 162, 301
Tombac, 181–190
color of, 182
composition of, 182
derivation of the term, 181
properties of, 181
Tools, tempering of, 387
Toucas's alloy, 318, 319
Touchstone, 506, 507
Toulouse, France, weight of large bell in, 227
Tournay's metal, 186
Tournu-Leonard's alloy, 420
Tubes, tough brass for, 153, 154
Tungsten, 42, 43
group, 42–45
-steel, 393–396
analyses of, 395, 396
fracture of, 395
magnetic retentiveness of, 395
tests of, 394, 395
Type, alloys suitable for casting, 368
manufacture of, 369
metal, 367–370
alloy for, 357

UCHATIUS bronze, 225, 226
experiments of, 98, 99
United States, zinc in the, 38
Uranium, 38

VALVE-BALLS, bronze for, 239, 240
Vanadate, 400
Vanadite, 43
Vanadium, 43–45
alloying power of, 44, 45
-chrome steels, 402, 403
discovery of, 396
experiments showing influence of, on chrome, 403
-nickel steel, 401, 402
preparation of, 44
properties of, 44
results obtained by the addition of, to steel, 401
-steel, 396–403
bending tests of, 398, 399
classes of, 401–403
initial material for the preparation of, 400
tests of steel with and without, 398
Van der Ven, E., investigation by, of bronze for telephone lines, 253, 254
Victor metal, 475
Vienna, flux for hard soldering used in, 489
metallic cement, 451, 452
weight of large bell in, 227
Volborthite, 43

WARNE'S metal, 420
Waste metals, recovery of, 526–532
Watch manufacturers, alloys for, 442, 443
Watches, palladium-bearing metal for, 442
Watts, invention of shot-towers by, 372
Webster's bismuth bronze, 315
Webster Crown Metal Co., alloys made by, 354–356
Weiler's alloys, 251
West, Thomas D., on casting aluminium bronze, 346–349
White brass, 190–193
metal, 301
metallo-graphic examination of, 295, 296
metals, 294–305
for bearings, 398
White pig iron, 390
solder, 481
Wolfram, 43
Wood's metal, 112, 380
Wood-grain alloy, 418–420
Wrought iron, 61

YELLOW gold, 423
metal, 156, 157
solder, 481

Zinc, 38–40
affinity of, for lead, 366
alloying power of, 40
amalgam, 454
black on, 523
brands of, 150
brassing of, 523
bronzing liquids for, 517
change in the molecular structure of, 145, 146
coloring of, 522, 523
-copper alloy, pure, strength of, 98
alloys, elongations of, 101
value for the tensile strength of, 97
crystalline structure of, 145, 146
effect of, on bronzes, 203
on copper, 142, 143
for voltaic cells, amalgamation of, 454, 455
gray, yellow, brown to black colors on, 523
group, 38–42
increase in the strength of copper by an addition of, 97
-iron, 467
ores, manufacture of brass with the use of, 163–165
properties of, 39, 40
separation of an alloy in refining, 32, 33
lead from, 532
solution of, in iron, 33
testing for, 502
-tin alloys, hardness of, 103
liquation of, 69
-white, 39

CATALOGUE

OF

Practical and Scientific Books

PUBLISHED BY

HENRY CAREY BAIRD & CO.

INDUSTRIAL PUBLISHERS, BOOKSELLERS AND IMPORTERS.

810 Walnut Street, Philadelphia.

☞ Any of the Books comprised in this Catalogue will be sent by mail, free of postage, to any address in the world, at the publication prices.

☞ A Descriptive Catalogue, 90 pages, 8vo., will be sent free and free of postage, to any one in any part of the world, who will furnish his address.

☞ Where not otherwise stated, all of the Books in this Catalogue are bound in muslin.

AMATEUR MECHANICS' WORKSHOP:
A treatise containing plain and concise directions for the manipulation of Wood and Metals, including Casting, Forging, Brazing, Soldering and Carpentry. By the author of the "Lathe and Its Uses." Seventh edition. Illustrated. 8vo. . . . $2.50

ANDES.—Animal Fats and Oils:
Their Practical Production, Purification and Uses; their Properties, Falsification and Examination. 62 illustrations. 8vo.

ANDES.—Vegetable Fats and Oils:
Their Practical Preparation, Purification and Employment; their Properties, Adulteration and Examination. 94 illustrations. 8vo.

ARLOT.—A Complete Guide for Coach Painters:
Translated from the French of M. ARLOT, Coach Painter, for eleven years Foreman of Painting to M. Eherler, Coach Maker, Paris. By A. A. FESQUET, Chemist and Engineer. To which is added an Appendix, containing Information respecting the Materials and the Practice of Coach and Car Painting and Varnishing in the United States and Great Britain 12mo. . . . $1.25

ARMENGAUD, AMOROUX, AND JOHNSON.—The Practical Draughtsman's Book of Industrial Design, and Machinist's and Engineer's Drawing Companion:

Forming a Complete Course of Mechanical Engineering and Architectural Drawing. From the French of M. Armengaud the elder, Prof. of Design in the Conservatoire of Arts and Industry, Paris, and MM. Armengaud the younger, and Amoroux, Civil Engineers. Rewritten and arranged with additional matter and plates, selections from and examples of the most useful and generally employed mechanism of the day. By WILLIAM JOHNSON, Assoc. Inst. C. E. Illustrated by fifty folio steel plates, and fifty wood-cuts. A new edition, 4to, cloth. $6.00

ARMSTRONG.—The Construction and Management of Steam Boilers:

By R. ARMSTRONG, C. E. With an Appendix by ROBERT MALLET, C. E., F. R. S. Seventh Edition. Illustrated. 1 vol. 12mo. .60

ARROWSMITH.—The Paper-Hanger's Companion:

Comprising Tools, Pastes, Preparatory Work; Selection and Hanging of Wall-Papers; Distemper Painting and Cornice-Tinting; Stencil Work; Replacing Sash-Cord and Broken Window Panes; and Useful Wrinkles and Receipts, By JAMES ARROWSMITH. A New, Thoroughly Revised, and Much Enlarged Edition. Illustrated by 25 engravings, 162 pages. (1905) $1.00

ASHTON.—The Theory and Practice of the Art of Designing Fancy Cotton and Woollen Cloths from Sample:

Giving full instructions for reducing drafts, as well as the methods of spooling and making out harness for cross drafts and finding any required reed; with calculations and tables of yarn. By FREDERIC T. ASHTON, Designer, West Pittsfield, Mass. With fifty-two illustrations. One vol. folio $5.00

ASKINSON.—Perfumes and their Preparation:

A Comprehensive Treatise on Perfumery, containing Complete Directions for Making Handkerchief Perfumes, Smelling-Salts, Sachets, Fumigating Pastils; Preparations for the Care of the Skin, the Mouth, the Hair; Cosmetics, Hair Dyes, and other Toilet Articles. By G.W. ASKINSON. Translated from the German by ISIDOR FURST. Revised by CHARLES RICE. 32 Illustrations. 8vo. $3.00

BRONGNIART.—Coloring and Decoration of Ceramic Ware.

8vo. $2.50

BAIRD.—The American Cotton Spinner, and Manager's and Carder's Guide:

A Practical Treatise on Cotton Spinning; giving the Dimensions and Speed of Machinery, Draught and Twist Calculations, etc.; with notices of recent Improvements: together with Rules and Examples for making changes in the sizes and numbers of Roving and Yarn. Compiled from the papers of the late ROBERT H. BAIRD. 12mo.

$1.50

BAKER.—Long-Span Railway Bridges:
Comprising Investigations of the Comparative Theoretical and Practical Advantages of the various Adopted or Proposed Type Systems of Construction; with numerous Formulæ and Tables. By B. BAKER. 12mo. $1.00

BRANNT.—A Practical Treatise on Distillation and Rectification of Alcohol:
Comprising Raw Materials; Production of Malt, Preparation of Mashes and of Yeast; Fermentation; Distillation and Rectification and Purification of Alcohol; Preparation of Alcoholic Liquors, Liqueurs, Cordials, Bitters, Fruit Essences, Vinegar, etc.; Examination of Materials for the Preparation of Malt as well as of the Malt itself; Examination of Mashes before and after Fermentation; Alcoholometry, with Numerous Comprehensive Tables; and an Appendix on the Manufacture of Compressed Yeast and the Examination of Alcohol and Alcoholic Liquors for Fusel Oil and other Impurities. By WILLIAM T. BRANNT, Editor of "The Techno-Chemical Receipt Book." Second Edition. Entirely Rewritten. Illustrated by 105 engravings. 460 pages, 8vo. (Dec., 1903) . . . $4.00

BARR.—A Practical Treatise on the Combustion of Coal:
Including descriptions of various mechanical devices for the Economic Generation of Heat by the Combustion of Fuel, whether solid, liquid or gaseous 8vo. $2.50

BARR.—A Practical Treatise on High Pressure Steam Boilers:
Including Results of Recent Experimental Tests of Boiler Materials, together with a description of Approved Safety Apparatus, Steam Pumps, Injectors and Economizers in actual use. By WM. M. BARR. 204 Illustrations. 8vo. $3.00

BAUERMAN.—A Treatise on the Metallurgy of Iron:
Containing Outlines of the History of Iron Manufacture, Methods of Assay, and Analysis of Iron Ores, Processes of Manufacture of Iron and Steel, etc., etc. By H. BAUERMAN, F. G. S., Associate of the Royal School of Mines. Fifth Edition, Revised and Enlarged. Illustrated with numerous Wood Engravings from Drawings by J. B. JORDAN. 12mo, ... $2.00

BRANNT.—The Metallic Alloys: A Practical Guide
For the Manufacture of all kinds of Alloys, Amalgams, and Solders, used by Metal-Workers; together with their Chemical and Physical Properties and their Application in the Arts and the Industries; with an Appendix on the Coloring of Alloys and the Recovery of Waste Metals. By WILLIAM T. BRANNT. 34 Engravings. A New, Revised, and Enlarged Edition. 554 pages. 8vo. . . $4.50

BEANS.—A Treatise on Railway Curves and Location of Railroads:
By E. W. BEANS, C. E. Illustrated. 12mo. Tucks. . $1.50

BELL.—Carpentry Made Easy:
Or, The Science and Art of Framing on a New and Improved System. With Specific Instructions for Building Balloon Frames, Barn Frames, Mill Frames, Warehouses, Church Spires, etc. Comprising also a System of Bridge Building, with Bills, Estimates of Cost, and valuable Tables. Illustrated by forty-four plates, comprising nearly 200 figures. By WILLIAM E. BELL, Architect and Practical Builder. 8vo. $5.00

BEMROSE.—Fret-Cutting and Perforated Carving:
With fifty-three practical illustrations. By W. BEMROSE, JR. 1 vol. quarto $2.50

BEMROSE.—Manual of Buhl-work and Marquetry:
With Practical Instructions for Learners, and ninety colored designs. By W. BEMROSE, JR. 1 vol. quarto $3.00

BEMROSE.—Manual of Wood Carving:
With Practical Illustrations for Learners of the Art, and Original and Selected Designs. By WILLIAM BEMROSE, JR. With an Introduction by LLEWELLYN JEWITT, F. S. A., etc. With 128 illustrations, 4to. $2.50

BERSCH.—Cellulose, Cellulose Products, and Rubber Substitutes:
Comprising the Preparation of Cellulose, Parchment-Cellulose, Methods of Obtaining Sugar, Alcohol and Oxalic Acid from Wood-Cellulose; Production of Nitro-Cellulose and Cellulose Esters; Manufacture of Artificial Silk, Viscose, Celluloid, Rubber Substitutes, Oil-Rubber, and Faktis. By DR. JOSEPH BERSCH. Translated by WILLIAM T. BRANNT. 41 illustrations. (1904.) $3.00

BILLINGS.—Tobacco:
Its History, Variety, Culture, Manufacture, Commerce, and Various Modes of Use. By E. R. BILLINGS. Illustrated by nearly 200 engravings. 8vo. $3.00

BIRD.—The American Practical Dyers' Companion:
Comprising a Description of the Principal Dye-Stuffs and Chemicals used in Dyeing, their Natures and Uses; Mordants and How Made; with the best American, English, French and German processes for Bleaching and Dyeing Silk, Wool, Cotton, Linen, Flannel, Felt, Dress Goods, Mixed and Hosiery Yarns, Feathers, Grass, Felt, Fur, Wool, and Straw Hats, Jute Yarn, Vegetable Ivory, Mats, Skins, Furs, Leather, etc., etc. By Wood Aniline, and other Processes, together with Remarks on Finishing Agents, and instructions in the Finishing of Fabrics, Substitutes for Indigo, Water-Proofing of Materials, Tests and Purification of Water, Manufacture of Aniline and other New Dye Wares, Harmonizing Colors, etc., etc.; embracing in all over 800 Receipts for Colors and Shades, *accompanied by* 170 *Dyed Samples of Raw Materials and Fabrics.* By F. J. BIRD, Practical Dyer, Author of "The Dyers' Hand-Book." 8vo. $7.50

BLINN.—A Practical Workshop Companion for Tin, Sheet-Iron, and Copper-plate Workers:
Containing Rules for describing various kinds of Patterns used by Tin, Sheet-Iron and Copper-plate Workers; Practical Geometry; Mensuration of Surfaces and Solids; Tables of the Weights of Metals, Lead-pipe, etc.; Tables of Areas and Circumferences of Circles; Japan, Varnishes, Lackers, Cements, Compositions, etc., etc. By LEROY J. BLINN, Master Mechanic. With One Hundred and Seventy Illustrations. 12mo. $2.50

BOOTH.—Marble Worker's Manual:
Containing Practical Information respecting Marbles in general, their Cutting, Working and Polishing; Veneering of Marble; Mosaics; Composition and Use of Artificial Marble, Stuccos, Cements, Receipts, Secrets, etc., etc. Translated from the French by M. L. BOOTH. With an Appendix concerning American Marbles. 12mo., cloth $1.50

BRANNT.—A Practical Treatise on Animal and Vegetable Fats and Oils:
Comprising both Fixed and Volatile Oils, their Physical and Chemical Properties and Uses, the Manner of Extracting and Refining them, and Practical Rules for Testing them; as well as the Manufacture of Artificial Butter and Lubricants, etc., with lists of American Patents relating to the Extraction, Rendering, Refining, Decomposing, and Bleaching of Fats and Oils. By WILLIAM T. BRANNT, Editor of the "Techno-Chemical Receipt Book." Second Edition, Revised and in a great part Rewritten. Illustrated by 302 Engravings. In Two Volumes. 1304 pp. 8vo. $10.00

BRANNT.—A Practical Treatise on the Manufacture of Soap and Candles:
Based upon the most Recent Experiences in the Practice and Science; comprising the Chemistry, Raw Materials, Machinery, and Utensils and Various Processes of Manufacture, including a great variety of formulas. Edited chiefly from the German of Dr. C. Deite, A. Engelhardt, Dr. C. Schaedler and others; with additions and lists of American Patents relating to these subjects. By WM. T. BRANNT. Illustrated by 163 engravings. 677 pages. 8vo. . . $10.00

BRANNT.—India Rubber, Gutta-Percha and Balata:
Occurrence, Geographical Distribution, and Cultivation, Obtaining and Preparing the Raw Materials, Modes of Working and Utilizing them, Including Washing, Maceration, Mixing, Vulcanizing, Rubber and Gutta-Percha Compounds, Utilization of Waste, etc. By WILLIAM T. BRANNT. Illustrated. 12mo. (1900.) . . $3.00

BRANNT—WAHL.—The Techno-Chemical Receipt Book:
Containing several thousand Receipts covering the latest, most important, and most useful discoveries in Chemical Technology, and their Practical Application in the Arts and the Industries. Edited chiefly from the German of Drs. Winckler, Elsner, Heintze, Mierzinski, Jacobsen, Koller and Heinzerling, with additions by WM. T. BRANNT and WM. H. WAHL, Ph. D. Illustrated by 78 engravings. 12mo. 495 pages. $2.00

BROWN.—Five Hundred and Seven Mechanical Movements:
Embracing all those which are most important in Dynamics, Hydraulics, Hydrostatics, Pneumatics, Steam Engines, Mill and other Gearing, Presses, Horology, and Miscellaneous Machinery; and including many movements never before published, and several of which have only recently come into use. By HENRY T. BROWN. 12mo. $1.00

BUCKMASTER.—The Elements of Mechanical Physics:
By J. C. BUCKMASTER. Illustrated with numerous engravings. 12mo. $1.00

BULLOCK.—The American Cottage Builder:
A Series of Designs, Plans and Specifications, from $200 to $20,000, for Homes for the People; together with Warming, Ventilation, Drainage, Painting and Landscape Gardening. By JOHN BULLOCK, Architect and Editor of "The Rudiments of Architecture and Building," etc., etc. Illustrated by 75 engravings. 8vo. $2.50

BULLOCK.—The Rudiments of Architecture and Building:
For the use of Architects, Builders, Draughtsmen, Machinists, Engineers and Mechanics. Edited by JOHN BULLOCK, author of "The American Cottage Builder." Illustrated by 250 Engravings. 8vo. $2.50

BURGH.—Practical Rules for the Proportions of Modern Engines and Boilers for Land and Marine Purposes.
By N. P. BURGH, Engineer. 12mo. $1.50

BYLES.—Sophisms of Free Trade and Popular Political Economy Examined.
By a BARRISTER (SIR JOHN BARNARD BYLES, Judge of Common Pleas). From the Ninth English Edition, as published by the Manchester Reciprocity Association. 12mo. . . . $1.25

BOWMAN.—The Structure of the Wool Fibre in its Relation to the Use of Wool for Technical Purposes:
Being the substance, with additions, of Five Lectures, delivered at the request of the Council, to the members of the Bradford Technical College, and the Society of Dyers and Colorists. By F. H. BOWMAN, D. Sc., F. R. S. E., F. L. S. Illustrated by 32 engravings. 8vo. $7.50

BYRNE.—Hand-Book for the Artisan, Mechanic, and Engineer:
Comprising the Grinding and Sharpening of Cutting Tools, Abrasive Processes, Lapidary Work, Gem and Glass Engraving, Varnishing and Lackering, Apparatus, Materials and Processes for Grinding and

Polishing, etc. By OLIVER BYRNE. Illustrated by 185 wood engravings. 8vo. $5.00

BYRNE.—Pocket-Book for Railroad and Civil Engineers:
Containing New, Exact and Concise Methods for Laying out Railroad Curves, Switches, Frog Angles and Crossings; the Staking out of work; Levelling; the Calculation of Cuttings: Embankments; Earthwork, etc. By OLIVER BYRNE. 18mo., full bound, pocket-book form $1.50

BYRNE.—The Practical Metal-Worker's Assistant:
Comprising Metallurgic Chemistry; the Arts of Working all Metals and Alloys; Forging of Iron and Steel; Hardening and Tempering; Melting and Mixing; Casting and Founding; Works in Sheet Metal; the Processes Dependent on the Ductility of the Metals; Soldering; and the most Improved Processes and Tools employed by Metal-Workers. With the Application of the Art of Electro-Metallurgy to Manufacturing Processes; collected from Original Sources, and from the works of Holtzapffel, Bergeron, Leupold, Plumier, Napier, Scoffern, Clay, Fairbairn and others. By OLIVER BYRNE. A new, revised and improved edition, to which is added an Appendix, containing The Manufacture of Russian Sheet-Iron. By JOHN PERCY, M. D., F. R. S. The Manufacture of Malleable Iron Castings, and Improvements in Bessemer Steel. By A. A. FESQUET, Chemist and Engineer. With over Six Hundred Engravings, Illustrating every Branch of the Subject. 8vo. $5.00

BYRNE.—The Practical Model Calculator:
For the Engineer, Mechanic, Manufacturer of Engine Work, Naval Architect, Miner and Millwright. By OLIVER BYRNE. 8vo., nearly 600 pages . . . . . (Scarce.)

CABINET MAKER'S ALBUM OF FURNITURE:
Comprising a Collection of Designs for various Styles of Furniture. Illustrated by Forty-eight Large and Beautifully Engraved Plates. Oblong, 8vo. $1.50

CALLINGHAM.—Sign Writing and Glass Embossing:
A Complete Practical Illustrated Manual of the Art. By JAMES CALLINGHAM. To which are added Numerous Alphabets and the Art of Letter Painting Made Easy. By JAMES C. BADENOCH. 258 pages. 12mo. $1.50

CAMPIN.—A Practical Treatise on Mechanical Engineering:
Comprising Metallurgy, Moulding, Casting, Forging, Tools, Work-shop Machinery, Mechanical Manipulation, Manufacture of Steam-Engines, etc. With an Appendix on the Analysis of Iron and Iron Ores. By FRANCIS CAMPIN, C. E. To which are added, Observations on the Construction of Steam Boilers, and Remarks upon Furnaces used for Smoke Prevention; with a Chapter on Explosions. By R. ARMSTRONG, C. E., and JOHN BOURNE. (Scarce.)

CAREY.—A Memoir of Henry C. Carey.
By DR. WM. ELDER. With a portrait. 8vo., cloth . . 75

CAREY.—The Works of Henry C. Carey:

Harmony of Interests: Agricultural, Manufacturing and Commercial. 8vo. $1.25

Manual of Social Science. Condensed from Carey's "Principles of Social Science." By KATE MCKEAN. 1 vol. 12mo. . $2.00

Miscellaneous Works. With a Portrait. 2 vols. 8vo. $10.00

Past, Present and Future. 8vo. $2.50

Principles of Social Science. 3 volumes, 8vo. . . $7.50

The Slave-Trade, Domestic and Foreign; Why it Exists, and How it may be Extinguished (1853). 8vo. . . . $2.00

The Unity of Law: As Exhibited in the Relations of Physical, Social, Mental and Moral Science (1872). 8vo. . . $2.50

CLARK.—Tramways, their Construction and Working:
Embracing a Comprehensive History of the System. With an exhaustive analysis of the various modes of traction, including horse-power, steam, heated water and compressed air; a description of the varieties of Rolling stock, and ample details of cost and working expenses. By D. KINNEAR CLARK. Illustrated by over 200 wood engravings, and thirteen folding plates. 1 vol. 8vo. . $5.00

COLBURN.—The Locomotive Engine:
Including a Description of its Structure, Rules for Estimating its Capabilities, and Practical Observations on its Construction and Management. By ZERAH COLBURN. Illustrated. 12mo. . $1.00

COLLENS.—The Eden of Labor; or, the Christian Utopia.
By T. WHARTON COLLENS, author of "Humanics," "The History of Charity," etc. 12mo. Paper cover, $1.00; Cloth . $1.25

COOLEY.—A Complete Practical Treatise on Perfumery:
Being a Hand-book of Perfumes, Cosmetics and other Toilet Articles. With a Comprehensive Collection of Formulæ. By ARNOLD J. COOLEY. 12mo. $1.50

COOPER.—A Treatise on the use of Belting for the Transmission of Power.
With numerous illustrations of approved and actual methods of arranging Main Driving and Quarter Twist Belts, and of Belt Fastenings. Examples and Rules in great number for exhibiting and calculating the size and driving power of Belts. Plain, Particular and Practical Directions for the Treatment, Care and Management of Belts. Descriptions of many varieties of Beltings, together with chapters on the Transmission of Power by Ropes; by Iron and Wood Frictional Gearing; on the Strength of Belting Leather; and on the Experimental Investigations of Morin, Briggs, and others. By JOHN H. COOPER, M. E. 8vo. $3.50

CRAIK.—The Practical American Millwright and Miller.
By DAVID CRAIK, Millwright. Illustrated by numerous wood engravings and two folding plates. 8vo. . . . (Scarce.)

CROSS.—The Cotton Yarn Spinner:
Showing how the Preparation should be arranged for Different Counts of Yarns by a System more uniform than has hitherto been practiced; by having a Standard Schedule from which we make all our Changes. By RICHARD CROSS. 122 pp. 12mo. . 75

CRISTIANI.—A Technical Treatise on Soap and Candles:
With a Glance at the Industry of Fats and Oils. By R. S. CRISTIANI, Chemist. Author of "Perfumery and Kindred Arts." Illustrated by 176 engravings. 581 pages, 8vo. $15.00

COURTNEY.—The Boiler Maker's Assistant in Drawing, Templating, and Calculating Boiler Work and Tank Work, etc.
Revised by D. K. CLARK. 102 ills. Fifth edition. . . 80

COURTNEY.—The Boiler Maker's Ready Reckoner:
With Examples of Practical Geometry and Templating. Revised by D. K. CLARK, C. E. 37 illustrations. Fifth edition. . $1.60

DAVIDSON.—A Practical Manual of House Painting, Graining, Marbling, and Sign-Writing:
Containing full information on the processes of House Painting in Oil and Distemper, the Formation of Letters and Practice of Sign-Writing, the Principles of Decorative Art, a Course of Elementary Drawing for House Painters, Writers, etc., and a Collection of Useful Receipts. With nine colored illustrations of Woods and Marbles, and numerous wood engravings. By ELLIS A. DAVIDSON. 12mo. $2.00

DAVIES.—A Treatise on Earthy and Other Minerals and Mining:
By D. C. DAVIES, F. G. S., Mining Engineer, etc. Illustrated by 76 Engravings. 12mo. $5.00

DAVIES.—A Treatise on Metalliferous Minerals and Mining:
By D. C. DAVIES, F. G. S, Mining Engineer, Examiner of Mines, Quarries and Collieries. Illustrated by 148 engravings of Geological Formations, Mining Operations and Machinery, drawn from the practice of all parts of the world. Fifth Edition, thoroughly Revised and much Enlarged by his son, E. Henry Davies. 12mo., 524 pages $5.00

DAVIES.—A Treatise on Slate and Slate Quarrying:
Scientific, Practical and Commercial. By D. C. DAVIES, F. G. S., Mining Engineer, etc. With numerous illustrations and folding plates. 12mo. $1.20

DAVIS.—A Practical Treatise on the Manufacture of Brick, Tiles and Terra-Cotta:
Including Stiff Clay, Dry Clay, Hand Made, Pressed or Front, and Roadway Paving Brick, Enamelled Brick, with Glazes and Colors, Fire Brick and Blocks, Silica Brick, Carbon Brick, Glass Pots, Re-

torts, Architectural Terra-Cotta, Sewer Pipe, Drain Tile, Glazed and Unglazed Roofing Tile, Art Tile, Mosaics, and Imitation of Intarsia or Inlaid Surfaces. Comprising every product of Clay employed in Architecture, Engineering, and the Blast Furnace. With a Detailed Description of the Different Clays employed, the Most Modern Machinery, Tools, and Kilns used, and the Processes for Handling, Disintegrating, Tempering, and Moulding the Clay into Shape, Drying, Setting, and Burning. By Charles Thomas Davis. Third Edition. Revised and in great part rewritten. Illustrated by 261 engravings. 662 pages $12.50

DAVIS.—A Treatise on Steam-Boiler Incrustation and Methods for Preventing Corrosion and the Formation of Scale:
By CHARLES T. DAVIS. Illustrated by 65 engravings. 8vo.

DAVIS.—The Manufacture of Paper:
Being a Description of the various Processes for the Fabrication, Coloring and Finishing of every kind of Paper, Including the Different Raw Materials and the Methods for Determining their Values, the Tools, Machines and Practical Details connected with an intelligent and a profitable prosecution of the art, with special reference to the best American Practice. To which are added a History of Paper, complete Lists of Paper-Making Materials, List of American Machines, Tools and Processes used in treating the Raw Materials, and in Making, Coloring and Finishing Paper. By CHARLES T. DAVIS. Illustrated by 156 engravings. 608 pages, 8vo. $6.00

DAVIS.—The Manufacture of Leather:
Being a Description of all the Processes for the Tanning and Tawing with Bark, Extracts, Chrome and all Modern Tannages in General Use, and the Currying, Finishing and Dyeing of Every Kind of Leather; Including the Various Raw Materials, the Tools, Machines, and all Details of Importance Connected with an Intelligent and Profitable Prosecution of the Art, with Special Reference to the Best American Practice. To which are added Lists of American Patents (1884–1897) for Materials, Processes, Tools and Machines for Tanning, Currying, etc. By CHARLES THOMAS DAVIS. Second Edition, Revised, and in great part Rewritten. Illustrated by 147 engravings and 14 Samples of Quebracho Tanned and Aniline Dyed Leathers. 8vo, cloth, 712 pages. Price $10.00

DAWIDOWSKY—BRANNT.—A Practical Treatise on the Raw Materials and Fabrication of Glue, Gelatine, Gelatine Veneers and Foils, Isinglass, Cements, Pastes, Mucilages, etc.:
Based upon Actual Experience. By F. DAWIDOWSKY, Technical Chemist. Translated from the German, with extensive additions, including a description of the most Recent American Processes, by WILLIAM T. BRANNT. 2d revised edition, 350 pages. (1905.)
Price $3.00

DE GRAFF.—The Geometrical Stair-Builders' Guide:
Being a Plain Practical System of Hand-Railing, embracing all its necessary Details, and Geometrically Illustrated by twenty-two Steel Engravings; together with the use of the most approved principles of Practical Geometry By SIMON DE GRAFF, Architect (Scarce.)

DE KONINCK—DIETZ.—A Practical Manual of Chemical Analysis and Assaying:

As applied to the Manufacture of Iron from its Ores, and to Cast Iron, Wrought Iron, and Steel, as found in Commerce. By L. L. DE KONINCK, Dr. Sc., and E. DIETZ, Engineer. Edited with Notes, by ROBERT MALLET, F. R. S., F. S. G., M. I. C. E., etc. American Edition, Edited with Notes and an Appendix on Iron Ores, by A. A. FESQUET, Chemist and Engineer. 12mo. . . . $1.50

UNCAN.—Practical Surveyor's Guide:

Containing the necessary information to make any person of common capacity, a finished land surveyor without the aid of a teacher. By ANDREW DUNCAN. Revised. 72 engravings, 214 pp. 12mo. $1.50

DUPLAIS.—A Treatise on the Manufacture and Distillation of Alcoholic Liquors:

Comprising Accurate and Complete Details in Regard to Alcohol from Wine, Molasses, Beets, Grain, Rice, Potatoes, Sorghum, Asphodel, Fruits, etc.; with the Distillation and Rectification of Brandy, Whiskey, Rum, Gin, Swiss Absinthe, etc., the Preparation of Aromatic Waters, Volatile Oils or Essences, Sugars, Syrups, Aromatic Tinctures, Liqueurs, Cordial Wines, Effervescing Wines, etc., the Ageing of Brandy and the improvement of Spirits, with Copious Directions and Tables for Testing and Reducing Spirituous Liquors, etc., etc. Translated and Edited from the French of MM. DUPLAIS, By M. MCKENNIE, M. D. Illustrated. 743 pp. 8vo. $15.00

DYER AND COLOR-MAKER'S COMPANION:

Containing upwards of two hundred Receipts for making Colors, on the most approved principles, for all the various styles and fabrics now in existence; with the Scouring Process, and plain Directions for Preparing, Washing-off, and Finishing the Goods. 12mo. $1 00

EIDHERR.—The Techno-Chemical Guide to Distillation:

A Hand-Book for the Manufacture of Alcohol and Alcoholic Liquors, including the Preparation of Malt and Compressed Yeast. Edited from the German of Ed. Eidherr.

EDWARDS.—A Catechism of the Marine Steam-Engine,

For the use of Engineers, Firemen, and Mechanics. A Practical Work for Practical Men. By EMORY EDWARDS, Mechanical Engineer. Illustrated by sixty-three Engravings, including examples of the most modern Engines. Third edition, thoroughly revised, with much additional matter. 12mo. 414 pages . . . $2 00

EDWARDS.—Modern American Locomotive Engines,

Their Design, Construction and Management. By EMORY EDWARDS. Illustrated 12mo. $2.00

EDWARDS.—The American Steam Engineer:

Theoretical and Practical, with examples of the latest and most approved American practice in the design and construction of Steam Engines and Boilers. For the use of engineers, machinists, boiler-makers, and engineering students. By EMORY EDWARDS. Fully illustrated, 419 pages. 12mo. $2.50

EDWARDS.—Modern American Marine Engines, Boilers, and Screw Propellers,

Their Design and Construction. Showing the Present Practice of the most Eminent Engineers and Marine Engine Builders in the United States. Illustrated by 30 large and elaborate plates. 4to. $5.00

EDWARDS.—The Practical Steam Engineer's Guide

In the Design, Construction, and Management of American Stationary, Portable, and Steam Fire-Engines, Steam Pumps, Boilers. Injectors, Governors, Indicators, Pistons and Rings, Safety Valves and Steam Gauges. For the use of Engineers, Firemen, and Steam Users. By EMORY EDWARDS. Illustrated by 119 engravings. 420 pages. 12mo. $2 50

EISSLER.—The Metallurgy of Silver:

A Practical Treatise on the Amalgamation, Roasting, and Lixiviation of Silver Ores, including the Assaying, Melting, and Refining of Silver Bullion. By M. EISSLER. 124 Illustrations. 336 pp. 12mo. $4.25

ELDER.—Conversations on the Principal Subjects of Political Economy.

By DR. WILLIAM ELDER. 8vo. $2.50

ELDER.—Questions of the Day,

Economic and Social. By DR. WILLIAM ELDER. 8vo. . $3.00

ERNI AND BROWN.—Mineralogy Simplified.

Easy Methods of Identifying Minerals, including Ores, by Means of the Blow-pipe, by Flame Reactions, by Humid Chemical Analysis, and by Physical Tests. By HENRI ERNI, A. M., M. D. Third Edition, revised, re-arranged and with the addition of entirely new matter, including Tables for the Determination of Minerals by Chemical and Pyrognostic Characters, and by Physical Characters By AMOS P. BROWN, E. M., Ph. D. 350 pp., illustrated by 96 engravings, pocket-book form, full flexible morocco, gilt edges $2.50

FAIRBAIRN. The Principles of Mechanism and Machinery of Transmission:

Comprising the Principles of Mechanism, Wheels, and Pulleys, Strength and Proportion of Shafts, Coupling of Shafts, and Engaging and Disengaging Gear. By SIR WILLIAM FAIRBAIRN, Bart. C. E. Beautifully illustrated by over 150 wood-cuts. In one volume, 12mo. $2.00

FLEMING.—Narrow Gauge Railways in America:

A Sketch of their Rise, Progress, and Success. Valuable Statistics as to Grades, Curves, Weight of Rail, Locomotives, Cars, etc. By HOWARD FLEMING. Illustrated, 8vo. $1.00

FORSYTH.—Book of Designs for Headstones, Mural, and other Monuments:

Containing 78 Designs. By JAMES FORSYTH, With an Introduction by CHARLES BOUTELL, M. A. 4to., cloth . . . $3.50

FRIEDBERG. Utilization of Bones by Chemical Means; especially the Modes of Obtaining Fat, Glue, Manures, Phosphorus and Phosphates.

Illustrated. 8vo. (In preparation.)

FRANKEL—HUTTER.—A Practical Treatise on the Manufacture of Starch, Glucose, Starch-Sugar, and Dextrine:
Based on the German of LADISLAUS VON WAGNER, Professor in the Royal Technical High School, Buda-Pest, Hungary, and other authorities. By JULIUS FRANKEL, Graduate of the Polytechnic School of Hanover. Edited by ROBERT HUTTER, Chemist, Practical Manufacturer of Starch-Sugar. Illustrated by 58 engravings, covering every branch of the subject, including examples of the most Recent and Best American Machinery. 8vo., 344 pp. $6.00

GARDNER.—The Painter's Encyclopædia:
Containing Definitions of all Important Words in the Art of Plain and Artistic Painting, with Details of Practice in Coach, Carriage, Railway Car, House, Sign, and Ornamental Painting, including Graining, Marbling, Staining, Varnishing, Polishing, Lettering, Stenciling, Gilding, Bronzing, etc. By FRANKLIN B. GARDNER. 158 Illustrations. 12mo. 427 pp. $2.00

GARDNER.—Everybody's Paint Book:
A Complete Guide to the Art of Outdoor and Indoor Painting. 38 illustrations. 12mo, 183 pp. $1.00

GEE.—The Jeweller's Assistant in the Art of Working in Gold:
A Practical Treatise for Masters and Workmen. 12mo. . $3.00

GEE.—The Goldsmith's Handbook:
Containing full instructions for the Alloying and Working of Gold, including the Art of Alloying, Melting, Reducing, Coloring, Collecting, and Refining; the Processes of Manipulation, Recovery of Waste; Chemical and Physical Properties of Gold; with a New System of Mixing its Alloys; Solders, Enamels, and other Useful Rules and Recipes. By GEORGE E. GEE. 12mo. . . $1.25

GEE.—The Silversmith's Handbook:
Containing full instructions for the Alloying and Working of Silver, including the different modes of Refining and Melting the Metal; its Solders; the Preparation of Imitation Alloys; Methods of Manipulation; Prevention of Waste; Instructions for Improving and Finishing the Surface of the Work; together with other Useful Information and Memoranda. By GEORGE E. GEE. Illustrated. 12mo. $1.25

GOTHIC ALBUM FOR CABINET-MAKERS:
Designs for Gothic Furniture. Twenty-three plates. Oblong $1.50

GRANT.—A Handbook on the Teeth of Gears:
Their Curves, Properties, and Practical Construction. By GEORGE B. GRANT. Illustrated. Third Edition, enlarged. 8vo. $1.00

GREENWOOD.—Steel and Iron:
Comprising the Practice and Theory of the Several Methods Pursued in their Manufacture, and of their Treatment in the Rolling-Mills, the Forge, and the Foundry. By WILLIAM HENRY GREENWOOD, F. C. S. With 97 Diagrams, 536 pages. 12mo. $1.75

GREGORY.—Mathematics for Practical Men:

Adapted to the Pursuits of Surveyors, Architects, Mechanics, and Civil Engineers. By OLINTHUS GREGORY. 8vo., plates $3.00

GRISWOLD.—Railroad Engineer's Pocket Companion for the Field:

Comprising Rules for Calculating Deflection Distances and Angles, Tangential Distances and Angles, and all Necessary Tables for Engineers; also the Art of Levelling from Preliminary Survey to the Construction of Railroads, intended Expressly for the Young Engineer, together with Numerous Valuable Rules and Examples. By W. GRISWOLD. 12mo., tucks $1.50

GRUNER.—Studies of Blast Furnace Phenomena:

By M. L. GRUNER, President of the General Council of Mines of France, and lately Professor of Metallurgy at the Ecole des Mines. Translated, with the author's sanction, with an Appendix, by L. D. B. GORDON, F. R. S. E., F. G. S. 8vo. . . . $2.50

Hand-Book of Useful Tables for the Lumberman, Farmer and Mechanic:

Containing Accurate Tables of Logs Reduced to Inch Board Measure, Plank, Scantling and Timber Measure; Wages and Rent, by Week or Month; Capacity of Granaries, Bins and Cisterns; Land Measure, Interest Tables, with Directions for Finding the Interest on any sum at 4, 5, 6, 7 and 8 per cent., and many other Useful Tables. 32 mo., boards. 186 pages 25

HASERICK.—The Secrets of the Art of Dyeing Wool, Cotton, and Linen,

Including Bleaching and Coloring Wool and Cotton Hosiery and Random Yarns. A Treatise based on Economy and Practice. By E. C. HASERICK. *Illustrated by* 323 *Dyed Patterns of the Yarns or Fabrics.* 8vo. $5.00

HATS AND FELTING:

A Practical Treatise on their Manufacture. By a Practical Hatter. Illustrated by Drawings of Machinery, etc. 8vo. . . $1.00

HERMANN.—Painting on Glass and Porcelain, and Enamel Painting:

A Complete Introduction to the Preparation of all the Colors and Fluxes Used for Painting on Glass, Porcelain, Enamel, Faience and Stoneware, the Color Pastes and Colored Glasses, together with a Minute Description of the Firing of Colors and Enamels, on the Basis of Personal Practical Experience of the Art up to Date. 18 illustrations. Second edition. . . . . .

HAUPT.—Street Railway Motors:

With Descriptions and Cost of Plants and Operation of the Various Systems now in Use. 12mo $1.75

HAUPT.—A Manual of Engineering Specifications and Contracts.

By LEWIS M. HAUPT, C. E. Illustrated with numerous maps. 328pp. 8vo. $3 00

HAUPT.—The Topographer, His Instruments and Methods.

By LEWIS M. HAUPT, A. M., C. E. Illustrated with numerous plates, maps and engravings. 247 pp. 8vo. . . . $3.00

HUGHES.—American Miller and Millwright's Assistant:

By WILLIAM CARTER HUGHES. 12mo. $1.50

HULME.—Worked Examination Questions in Plane Geometrical Drawing:

For the Use of Candidates for the Royal Military Academy, Woolwich; the Royal Military College, Sandhurst; the Indian Civil Engineering College, Cooper's Hill; Indian Public Works and Telegraph Departments; Royal Marine Light Infantry; the Oxford and Cambridge Local Examinations, etc. By F. EDWARD HULME, F. L. S., F. S. A., Art-Master Marlborough College. Illustrated by 300 examples. Small quarto $1.5

JERVIS.—Railroad Property:

A Treatise on the Construction and Management of Railways; designed to afford useful knowledge, in the popular style, to the holders of this class of property; as well as Railway Managers, Officers, and Agents. By JOHN B. JERVIS, late Civil Engineer of the Hudson River Railroad, Croton Aqueduct, etc. 12mo., cloth $1.50

KEENE.—A Hand-Book of Practical Gauging:

For the Use of Beginners, to which is added a Chapter on Distillation, describing the process in operation at the Custom-House for ascertaining the Strength of Wines. By JAMES B. KEENE, of H. M. Customs. 8vo. $1.00

KELLEY.—Speeches, Addresses, and Letters on Industrial and Financial Questions:

By HON. WILLIAM D. KELLEY, M. C. 544 pages, 8vo. . $2.50

KELLOGG.—A New Monetary System:

The only means of Securing the respective Rights of Labor and Property, and of Protecting the Public from Financial Revulsions. By EDWARD KELLOGG. 12mo. Paper cover, $1.00. Bound in cloth. $1.25

KEMLO.—Watch-Repairer's Hand-Book:

Being a Complete Guide to the Young Beginner, in Taking Apart, Putting Together, and Thoroughly Cleaning the English Lever and other Foreign Watches, and all American Watches. By F. KEMLO, Practical Watchmaker. With Illustrations. 12mo. $1.25

KENTISH.—A Treatise on a Box of Instruments,
And the Slide Rule; with the Theory of Trigonometry and Logarithms, including Practical Geometry, Surveying, Measuring of Timber, Cask and Malt Gauging, Heights, and Distances. By THOMAS KENTISH. In one volume. 12mo. $1.00

KERL.—The Assayer's Manual:
An Abridged Treatise on the Docimastic Examination of Ores, and Furnace and other Artificial Products. By BRUNO KERL, Professor in the Royal School of Mines. Translated from the German by WILLIAM T. BRANNT. Second American edition, edited with Extensive Additions by F. LYNWOOD GARRISON, Member of the American Institute of Mining Engineers, etc. Illustrated by 87 engravings. 8vo. (Third Edition in preparation.)

KICK.—Flour Manufacture.
A Treatise on Milling Science and Practice. By FREDERICK KICK Imperial Regierungsrath, Professor of Mechanical Technology in the Imperial German Polytechnic Institute, Prague. Translated from the second enlarged and revised edition with supplement by H. H. P. POWLES, Assoc. Memb. Institution of Civil Engineers. Illustrated with 28 Plates, and 167 Wood-cuts. 367 pages. 8vo. . $10.00

KINGZETT.—The History, Products, and Processes of the Alkali Trade:
Including the most Recent Improvements. By CHARLES THOMAS KINGZETT. Consulting Chemist. With 23 illustrations. 8vo. $2.50

KIRK.—The Cupola Furnace:
A Practical Treatise on the Construction and Management of Foundry Cupolas. By EDWARD KIRK, Practical Moulder and Melter, Consulting Expert in Melting. Illustrated by 78 engravings. Second Edition, revised and enlarged. 450 pages. 8vo. 1903. $3.50

LANDRIN.—A Treatise on Steel:
Comprising its Theory, Metallurgy, Properties, Practical Working, and Use. By M. H. C. LANDRIN, JR. From the French, by A. A. FESQUET. 12mo. $2.50

LANGBEIN.—A Complete Treatise on the Electro-Deposition of Metals:
Comprising Electro-Plating and Galvanoplastic Operations, the Deposition of Metals by the Contact and Immersion Processes, the Coloring of Metals, the Methods of Grinding and Polishing, as well as Descriptions of the Electric Elements, Dynamo-Electric Machines, Thermo-Piles and of the Materials and Processes used in Every Department of the Art. From the German of DR. GEORGE LANGBEIN, with additions by WM. T. BRANNT. Fifth Edition, thoroughly revised and much enlarged. 170 Engravings. 694 pages 8vo. 1905. $4.00

LARDNER.—The Steam-Engine:
For the Use of Beginners. Illustrated. 12mo. 60

LEHNER.—The Manufacture of Ink:
Comprising the Raw Materials, and the Preparation of Writing, Copying and Hektograph Inks, Safety Inks, Ink Extracts and Powders, etc. Translated from the German of SIGMUND LEHNER, with additions by WILLIAM T. BRANNT. Illustrated. 12mo. $2.00

LARKIN.—The Practical Brass and Iron Founder's Guide:
A Concise Treatise on Brass Founding, Moulding, the Metals and their Alloys, etc.; to which are added Recent Improvements in the Manufacture of Iron, Steel by the Bessemer Process, etc., etc. By JAMES LARKIN, late Conductor of the Brass Foundry Department in Reany, Neafie & Co.'s Penn Works, Philadelphia. New edition, revised, with extensive additions. 414 pages. 12mo. . $2.50

LEROUX.—A Practical Treatise on the Manufacture of Worsteds and Carded Yarns:
Comprising Practical Mechanics, with Rules and Calculations applied to Spinning; Sorting, Cleaning, and Scouring Wools; the English and French Methods of Combing, Drawing, and Spinning Worsteds, and Manufacturing Carded Yarns. Translated from the French of CHARLES LEROUX, Mechanical Engineer and Superintendent of a Spinning-Mill, by HORATIO PAINE, M. D., and A. A. FESQUET, Chemist and Engineer. Illustrated by twelve large Plates. To which is added an Appendix, containing Extracts from the Reports of the International Jury, and of the Artisans selected by the Committee appointed by the Council of the Society of Arts, London, on Woolen and Worsted Machinery and Fabrics, as exhibited in the Paris Universal Exposition, 1867. 8vo. $5.00

LEFFEL.—The Construction of Mill-Dams:
Comprising also the Building of Race and Reservoir Embankments and Head-Gates, the Measurement of Streams, Gauging of Water Supply, etc. By JAMES LEFFEL & Co. Illustrated by 58 engravings. 8vo. . . . . (Scarce.)

LESLIE.—Complete Cookery:
Directions for Cookery in its Various Branches. By MISS LESLIE. Sixtieth thousand. Thoroughly revised, with the addition of New Receipts. 12mo. $1.50

LE VAN.—The Steam Engine and the Indicator:
Their Origin and Progressive Development; including the Most Recent Examples of Steam and Gas Motors, together with the Indicator, its Principles, its Utility, and its Application. By WILLIAM BARNET LE VAN. Illustrated by 205 Engravings, chiefly of Indicator-Cards. 469 pp. 8vo. $2.00

LIEBER.—Assayer's Guide:
Or, Practical Directions to Assayers, Miners, and Smelters, for the Tests and Assays, by Heat and by Wet Processes, for the Ores of all the principal Metals, of Gold and Silver Coins and Alloys, and of Coal, etc. By OSCAR M. LIEBER. Revised. 283 pp. 12mo. $1.50

Lockwood's Dictionary of Terms:
Used in the Practice of Mechanical Engineering, embracing those Current in the Drawing Office, Pattern Shop, Foundry, Fitting, Turning, Smith's and Boiler Shops, etc., etc., comprising upwards of Six Thousand Definitions. Edited by a Foreman Pattern Maker, author of "Pattern Making." 417 pp. 12mo. . . . $3.75

LUKIN.—The Lathe and Its Uses:
Or Instruction in the Art of Turning Wood and Metal. Including a Description of the Most Modern Appliances for the Ornamentation of Plane and Curved Surfaces, an Entirely Novel Form of Lathe for Eccentric and Rose-Engine Turning; A Lathe and Planing Machine Combined; and Other Valuable Matter Relating to the Art. Illustrated by 462 engravings. Seventh edition. 315 pages. 8vo. $4.25

MAIN and BROWN.—Questions on Subjects Connected with the Marine Steam-Engine:
And Examination Papers; with Hints for their Solution. By THOMAS J. MAIN, Professor of Mathematics, Royal Naval College, and THOMAS BROWN, Chief Engineer, R. N. 12mo., cloth . $1.00

MAIN and BROWN.—The Indicator and Dynamometer:
With their Practical Applications to the Steam-Engine. By THOMAS J. MAIN, M. A. F. R., Ass't S. Professor Royal Naval College, Portsmouth, and THOMAS BROWN, Assoc. Inst. C. E., Chief Engineer R. N., attached to the R. N. College. Illustrated. 8vo. .

MAIN and BROWN.—The Marine Steam-Engine.
By THOMAS J. MAIN, F. R. Ass't S. Mathematical Professor at the Royal Naval College, Portsmouth, and THOMAS BROWN, Assoc. Inst. C. E., Chief Engineer R. N. Attached to the Royal Naval College. With numerous illustrations. 8vo. . .

MAKINS.—A Manual of Metallurgy:
By GEORGE HOGARTH MAKINS. 100 engravings. Second edition rewritten and much enlarged. 12mo., 592 pages . .

MARTIN.—Screw-Cutting Tables, for the Use of Mechanical Engineers:
Showing the Proper Arrangement of Wheels for Cutting the Threads of Screws of any Required Pitch; with a Table for Making the Universal Gas-Pipe Thread and Taps. By W. A. MARTIN, Engineer. 8vo. 50

MICHELL.—Mine Drainage:
Being a Complete and Practical Treatise on Direct-Acting Underground Steam Pumping Machinery. With a Description of a large number of the best known Engines, their General Utility and the Special Sphere of their Action, the Mode of their Application, and their Merits compared with other Pumping Machinery. By STEPHEN MICHELL. Illustrated by 247 engravings. 8vo., 369 pages. $12 50

MOLESWORTH.—Pocket-Book of Useful Formulæ and Memoranda for Civil and Mechanical Engineers.
By GUILFORD L. MOLESWORTH, Member of the Institution of Civil Engineers, Chief Resident Engineer of the Ceylon Railway. Full-bound in Pocket-book form $1.00

MOORE.—The Universal Assistant and the Complete Mechanic:

Containing over one million Industrial Facts, Calculations, Receipts, Processes, Trades Secrets, Rules, Business Forms, Legal Items, Etc., in every occupation, from the Household to the Manufactory. By R. MOORE. Illustrated by 500 Engravings. 12mo. . $2.50

MORRIS.—Easy Rules for the Measurement of Earthworks:

By means of the Prismoidal Formula. Illustrated with Numerous Wood-Cuts, Problems, and Examples, and concluded by an Extensive Table for finding the Solidity in cubic yards from Mean Areas. The whole being adapted for convenient use by Engineers, Surveyors, Contractors, and others needing Correct Measurements of Earthwork. By ELWOOD MORRIS, C. E. 8vo. $1.50

MAUCHLINE.—The Mine Foreman's Hand-Book

Of Practical and Theoretical Information on the Opening, Ventilating, and Working of Collieries. Questions and Answers on Practical and Theoretical Coal Mining. Designed to Assist Students and Others in Passing Examinations for Mine Foremanships. By ROBERT MAUCHLINE. 3d Edition. Thoroughly Revised and Enlarged by F. ERNEST BRACKETT. 134 engravings, 8vo. 378 pages. (1905) $3.75

NAPIER.—A System of Chemistry Applied to Dyeing.

By JAMES NAPIER, F. C. S. A New and Thoroughly Revised Edition. Completely brought up to the present state of the Science, including the Chemistry of Coal Tar Colors, by A. A. FESQUET, Chemist and Engineer. With an Appendix on Dyeing and Calico Printing, as shown at the Universal Exposition, Paris, 1867. Illustrated. 8vo. 422 pages $3.00

NEVILLE.—Hydraulic Tables, Coefficients, and Formulæ, for finding the Discharge of Water from Orifices, Notches Weirs, Pipes, and Rivers:

Third Edition, with Additions, consisting of New Formulæ for the Discharge from Tidal and Flood Sluices and Siphons; general information on Rainfall, Catchment-Basins, Drainage, Sewerage, Water Supply for Towns and Mill Power. By JOHN NEVILLE, C. E. M. R. I. A.; Fellow of the Royal Geological Society of Ireland. Thick 12mo. $5.50

NEWBERY.—Gleanings from Ornamental Art of every style:

Drawn from Examples in the British, South Kensington, Indian, Crystal Palace, and other Museums, the Exhibitions of 1851 and 1862, and the best English and Foreign works. In a series of 100 exquisitely drawn Plates, containing many hundred examples. By ROBERT NEWBERY. 4to. . . . . (Scarce.)

NICHOLLS.—The Theoretical and Practical Boiler-Maker and Engineer's Reference Book:

Containing a variety of Useful Information for Employers of Labor, Foremen and Working Boiler-Makers Iron, Copper, and Tinsmiths

Draughtsmen, Engineers, the General Steam-using Public, and for the Use of Science Schools and Classes. By SAMUEL NICHOLLS. Illustrated by sixteen plates, 12mo. $2.50

NICHOLSON.—A Manual of the Art of Bookbinding:

Containing full instructions in the different Branches of Forwarding, Gilding, and Finishing. Also, the Art of Marbling Book-edges and Paper. By JAMES B. NICHOLSON. Illustrated. 12mo., cloth $2.25

NICOLLS.—The Railway Builder:

A Hand-Book for Estimating the Probable Cost of American Railway Construction and Equipment. By WILLIAM J. NICOLLS, Civil Engineer. Illustrated, full bound, pocket-book form . $2.00

NORMANDY.—The Commercial Handbook of Chemical Analysis:

Or Practical Instructions for the Determination of the Intrinsic or Commercial Value of Substances used in Manufactures, in Trades, and in the Arts. By A. NORMANDY. New Edition, Enlarged, and to a great extent rewritten. By HENRY M. NOAD, Ph.D., F.R.S., thick 12mo. . . . . Scarce

NORRIS.—A Handbook for Locomotive Engineers and Machinists:

Comprising the Proportions and Calculations for Constructing Locomotives; Manner of Setting Valves; Tables of Squares, Cubes, Areas, etc., etc. By SEPTIMUS NORRIS, M. E. New edition. Illustrated, 12mo. $1.50

NYSTROM.—A New Treatise on Elements of Mechanics:

Establishing Strict Precision in the Meaning of Dynamical Terms; accompanied with an Appendix on Duodenal Arithmetic and Metrology. By JOHN W. NYSTROM, C. E. Illustrated. 8vo.

NYSTROM.—On Technological Education and the Construction of Ships and Screw Propellers:

For Naval and Marine Engineers. By JOHN W. NYSTROM, late Acting Chief Engineer, U. S. N. Second edition, revised, with additional matter. Illustrated by seven engravings. 12mo. . $1.

O'NEILL.—A Dictionary of Dyeing and Calico Printing:

Containing a brief account of all the Substances and Processes used in the Art of Dyeing and Printing Textile Fabrics; with Practical Receipts and Scientific Information. By CHARLES O'NEILL, Analytical Chemist. To which is added an Essay on Coal Tar Colors and their application to Dyeing and Calico Printing. By A. A. FESQUET, Chemist and Engineer. With an appendix on Dyeing and Calico Printing, as shown at the Universal Exposition, Paris, 1867 8vo., 491 pages $3.00

ORTON.—Underground Treasures:

How and Where to Find Them. A Key for the Ready Determination of all the Useful Minerals within the United States. By JAMES ORTON, A.M., Late Professor of Natural History in Vassar College, N. Y; author of the "Andes and the Amazon," etc. A New Edition, with An Appendix on Ore Deposits and Testing Minerals (1901). Illustrated $1.50

OSBORN.—The Prospector's Field Book and Guide.
In the Search For and the Easy Determination of Ores and Other Useful Minerals. By Prof. H. S. OSBORN, LL. D. Illustrated by 66 Engravings. Sixth Edition. Revised and Enlarged. 360 pages, 12mo. (Dec., 1903) $1.50

OSBORN—A Practical Manual of Minerals, Mines and Mining:
Comprising the Physical Properties, Geologic Positions, Local Occurrence and Associations of the Useful Minerals; their Methods of Chemical Analysis and Assay; together with Various Systems of Excavating and Timbering, Brick and Masonry Work, during Driving, Lining, Bracing and other Operations, etc. By Prof. H. S. OSBORN, LL. D., Author of "The Prospector's Field-Book and Guide." 171 engravings. Second Edition, revised. 8vo. $4.50

OVERMAN.—The Manufacture of Steel:
Containing the Practice and Principles of Working and Making Steel. A Handbook for Blacksmiths and Workers in Steel and Iron, Wagon Makers, Die Sinkers, Cutlers, and Manufacturers of Files and Hardware, of Steel and Iron, and for Men of Science and Art. By FREDERICK OVERMAN, Mining Engineer, Author of the "Manufacture of Iron," etc. A new, enlarged, and revised Edition. By A. A. FESQUET, Chemist and Engineer. 12mo. . . $1.50

OVERMAN.—The Moulder's and Founder's Pocket Guide:
A Treatise on Moulding and Founding in Green-sand, Dry-sand, Loam, and Cement; the Moulding of Machine Frames, Mill-gear, Hollow-ware, Ornaments, Trinkets, Bells, and Statues; Description of Moulds for Iron, Bronze, Brass, and other Metals; Plaster of Paris, Sulphur, Wax, etc.; the Construction of Melting Furnaces, the Melting and Founding of Metals; the Composition of Alloys and their Nature, etc., etc. By FREDERICK OVERMAN, M. E. A new Edition, to which is added a Supplement on Statuary and Ornamental Moulding, Ordnance, Malleable Iron Castings, etc. By A. A. FESQUET, Chemist and Engineer. Illustrated by 44 engravings. 12mo. . $2.00

PAINTER, GILDER, AND VARNISHER'S COMPANION.
Comprising the Manufacture and Test of Pigments, the Arts of Painting, Graining, Marbling, Staining, Sign-writing, Varnishing, Glass-staining, and Gilding on Glass; together with Coach Painting and Varnishing, and the Principles of the Harmony and Contrast of Colors. Twenty-seventh Edition. Revised, Enlarged, and in great part Rewritten. By WILLIAM T. BRANNT, Editor of "Varnishes, Lacquers, Printing Inks and Sealing Waxes." Illustrated. 395 pp. 12mo. $1.50

PALLETT.—The Miller's, Millwright's, and Engineer's Guide.
By HENRY PALLETT. Illustrated. 12mo. . . . $2.00

PERCY.—The Manufacture of Russian Sheet-Iron.
By JOHN PERCY, M. D., F. R. S. Paper. . . . 25 cts.

PERKINS.—Gas and Ventilation:
Practical Treatise on Gas and Ventilation. Illustrated. 12mo. $1.25

PERKINS AND STOWE.—A New Guide to the Sheet-iron and Boiler Plate Roller:
Containing a Series of Tables showing the Weight of Slabs and Piles to Produce Boiler Plates, and of the Weight of Piles and the Sizes of Bars to produce Sheet-iron; the Thickness of the Bar Gauge in decimals; the Weight per foot, and the Thickness on the Bar or Wire Gauge of the fractional parts of an inch; the Weight per sheet, and the Thickness on the Wire Gauge of Sheet-iron of various dimensions to weigh 112 lbs. per bundle; and the conversion of Short Weight into Long Weight, and Long Weight into Short. $1.50

POSSELT.—Recent Improvements in Textile Machinery Relating to Weaving:
Giving the Most Modern Points on the Construction of all Kinds of Looms, Warpers, Beamers, Slashers, Winders, Spoolers, Reeds, Temples, Shuttles, Bobbins, Heddles, Heddle Frames, Pickers, Jacquards, Card Stampers, etc., etc. 600 illus. . . $3 00

POSSELT.—Technology of Textile Design:
The Most Complete Treatise on the Construction and Application of Weaves for all Textile Fabrics and the Analysis of Cloth. By E. A. Posselt. 1,500 illustrations. 4to. $5.00

POSSELT.—Textile Calculations:
A Guide to Calculations Relating to the Manufacture of all Kinds of Yarns and Fabrics, the Analysis of Cloth, Speed, Power and Belt Calculations. By E. A. POSSELT. Illustrated. 4to. . $2.00

REGNAULT.—Elements of Chemistry:
By M. V. REGNAULT. Translated from the French by T. FORREST BETTON, M. D., and edited, with Notes, by JAMES C. BOOTH, Melter and Refiner U. S. Mint, and WILLIAM L. FABER, Metallurgist and Mining Engineer. Illustrated by nearly 700 wood-engravings. Comprising nearly 1,500 pages. In two volumes, 8vo., cloth . $6.00

RICHARDS.—Aluminium:
Its History, Occurrence, Properties, Metallurgy and Applications, including its Alloys. By JOSEPH W. RICHARDS, A. C., Chemist and Practical Metallurgist, Member of the Deutsche Chemische Gesellschaft. Illust. Third edition, enlarged and revised (1895) . $6.00

RIFFAULT, VERGNAUD, and TOUSSAINT.—A Practical Treatise on the Manufacture of Colors for Painting:
Comprising the Origin, Definition, and Classification of Colors; the Treatment of the Raw Materials; the best Formulæ and the Newest Processes for the Preparation of every description of Pigment, and the Necessary Apparatus and Directions for its Use; Dryers; the Testing, Application, and Qualities of Paints, etc., etc. By MM. RIFFAULT, VERGNAUD, and TOUSSAINT. Revised and Edited by M.

F. MALEPEYRE. **Translated from the French, by A. A. FESQUET, Chemist and Engineer. Illustrated by Eighty engravings. In one vol., 8vo., 659 pages $5.00**

ROPER.—Catechism for Steam Engineers and Electricians: Including the Construction and Management of Steam Engines, Steam Boilers and Electric Plants. By STEPHEN ROPER. Twenty-first edition, rewritten and greatly enlarged by E. R. KELLER and C. W. PIKE. 365 pages. Illustrations. 18mo., tucks, gilt. $2.00

ROPER.—Engineer's Handy Book: Containing Facts, Formulæ, Tables and Questions on Power, its Generation, Transmission and Measurement; Heat, Fuel, and Steam; The Steam Boiler and Accessories; Steam Engines and their Parts; Steam Engine Indicator; Gas and Gasoline Engines; Materials; their Properties and Strength; Together with a Discussion of the Fundamental Experiments in Electricity, and an Explanation of Dynamos, Motors, Batteries, etc., and Rules for Calculating Sizes of Wires. By STEPHEN ROPER. 15th edition. Revised and enlarged by E. R. KELLER, M. E. and C. W. PIKE, B. S. (1899), with numerous illustrations. Pocket-book form. Leather. $3.50

ROPER.—Hand-Book of Land and Marine Engines: Including the Modelling, Construction, Running, and Management of Land and Marine Engines and Boilers. With illustrations. By STEPHEN ROPER, Engineer. Sixth edition. 12mo., tucks, gilt edge. $3.50

ROPER.—Hand-Book of the Locomotive: Including the Construction of Engines and Boilers, and the Construction, Management, and Running of Locomotives. By STEPHEN ROPER. Eleventh edition. 18mo., tucks, gilt edge . $2.50

ROPER.—Hand-Book of Modern Steam Fire-Engines. With illustrations. By STEPHEN ROPER, Engineer. Fourth edition, 12mo., tucks, gilt edge $3.50

ROPER.—Questions and Answers for Engineers. This little book contains all the Questions that Engineers will be asked when undergoing an Examination for the purpose of procuring Licenses, and they are so plain that any Engineer or Fireman of ordinary intelligence may commit them to memory in a short time. By STEPHEN ROPER, Engineer. Third edition . . . $2.00

ROPER.—Use and Abuse of the Steam Boiler. By STEPHEN ROPER, Engineer. Eighth edition, with illustrations. 18mo., tucks, gilt edge $2.00

ROSE.—The Complete Practical Machinist: Embracing Lathe Work, Vise Work, Drills and Drilling, Taps and Dies, Hardening and Tempering, the Making and Use of Tools Tool Grinding, Marking out Work, Machine Tools, etc. By JOSHUA ROSE. 395 Engravings. Nineteenth Edition, greatly Enlarged with New and Valuable Matter. 12mo., 504 pages. . . $2.50

ROSE.—Mechanical Drawing Self-Taught: Comprising Instructions in the Selection and Preparation of Drawing Instruments, Elementary Instruction in Practical Mechanical Draw-

ing, together with Examples in Simple Geometry and Elementary Mechanism, including Screw Threads, Gear Wheels, Mechanical Motions, Engines and Boilers. By JOSHUA ROSE, M. E. Illustrated by 330 engravings. 8vo., 313 pages $4.00

ROSE.—The Slide-Valve Practically Explained:
Embracing simple and complete Practical Demonstrations of the operation of each element in a Slide-valve Movement, and illustrating the effects of Variations in their Proportions by examples carefully selected from the most recent and successful practice. By JOSHUA ROSE, M. E. Illustrated by 35 engravings . $1.00

ROSS.—The Blowpipe in Chemistry, Mineralogy and Geology:
Containing all Known Methods of Anhydrous Analysis, many Working Examples, and Instructions for Making Apparatus. By LIEUT.-COLONEL W. A. ROSS, R. A., F. G. S. With 120 Illustrations. 12mo. $2.00

SHAW.—Civil Architecture:
Being a Complete Theoretical and Practical System of Building, containing the Fundamental Principles of the Art. By EDWARD SHAW, Architect. To which is added a Treatise on Gothic Architecture, etc. By THOMAS W. SILLOWAY and GEORGE M. HARDING, Architects. The whole illustrated by 102 quarto plates finely engraved on copper. Eleventh edition. 4to. $6.00

SHUNK.—A Practical Treatise on Railway Curves and Location, for Young Engineers.
By W. F. SHUNK, C. E. 12mo. Full bound pocket-book form $2.00

SLATER.—The Manual of Colors and Dye Wares.
By J. W. SLATER. 12mo. $3.00

SLOAN.—American Houses:
A variety of Original Designs for Rural Buildings. Illustrated by 26 colored engravings, with descriptive references. By SAMUEL SLOAN, Architect. 8vo. 75

SLOAN.—Homestead Architecture:
Containing Forty Designs for Villas, Cottages, and Farm-houses, with Essays on Style, Construction, Landscape Gardening, Furniture, etc., etc. Illustrated by upwards of 200 engravings. By SAMUEL SLOAN, Architect. 8vo. $2.50

SLOANE.—Home Experiments in Science.
By T. O'CONOR SLOANE, E. M., A. M., PH. D. Illustrated by 91 engravings. 12mo. $1.00

SMEATON.—Builder's Pocket-Companion:
Containing the Elements of Building, Surveying, and Architecture; with Practical Rules and Instructions connected with the subject. By A. C. SMEATON, Civil Engineer, etc. 12mo.

SMITH.—A Manual of Political Economy.
By E. PESHINE SMITH. A New Edition, to which is added a full Index. 12mo. $1.25

SMITH.—Parks and Pleasure-Grounds:
Or Practical Notes on Country Residences, Villas, Public Parks, and Gardens. By CHARLES H. J. SMITH, Landscape Gardener and Garden Architect, etc., etc. 12mo. $2.00

SMITH.—The Dyer's Instructor:
Comprising Practical Instructions in the Art of Dyeing Silk, Cotton, Wool, and Worsted, and Woolen Goods; containing nearly 800 Receipts. To which is added a Treatise on the Art of Padding; and the Printing of Silk Warps, Skeins, and Handkerchiefs, and the various Mordants and Colors for the different styles of such work. By DAVID SMITH, Pattern Dyer. 12mo. . . . $1.50

SMYTH.—A Rudimentary Treatise on Coal and Coal-Mining.
By WARRINGTON W. SMYTH, M. A., F. R. G., President R. G. S., of Cornwall. Fifth edition, revised and corrected. With numerous illustrations. 12mo. $1.40

SNIVELY.—Tables for Systematic Qualitative Chemical Analysis.
By JOHN H. SNIVELY, Phr. D. 8vo. $1.00

SNIVELY.—The Elements of Systematic Qualitative Chemical Analysis:
A Hand-book for Beginners. By JOHN H. SNIVELY, Phr. D. 16mo. $2.00

STOKES.—The Cabinet-Maker and Upholsterer's Companion:
Comprising the Art of Drawing, as applicable to Cabinet Work; Veneering, Inlaying, and Buhl-Work; the Art of Dyeing and Staining Wood, Ivory, Bone, Tortoise-Shell, etc. Directions for Lackering, Japanning, and Varnishing; to make French Polish, Glues, Cements, and Compositions; with numerous Receipts, useful to workmen generally. By STOKES. Illustrated. A New Edition, with an Appendix upon French Polishing, Staining, Imitating, Varnishing, etc., etc. 12mo $1.25

STRENGTH AND OTHER PROPERTIES OF METALS;
Reports of Experiments on the Strength and other Properties of Metals for Cannon. With a Description of the Machines for Testing Metals, and of the Classification of Cannon in service. By Officers of the Ordnance Department, U. S. Army. By authority of the Secretary of War. Illustrated by 25 large steel plates. Quarto . $5.00

SULLIVAN.—Protection to Native Industry.
By Sir EDWARD SULLIVAN, Baronet, author of "Ten Chapters on Social Reforms." 8vo. $1.00

SHERRATT.—The Elements of Hand-Railing:
Simplified and Explained in Concise Problems that are Easily Understood. The whole illustrated with Thirty-eight Accurate and Original Plates, Founded on Geometrical Principles, and Showing how to Make Rail Without Centre Joints, Making Better Rail of the Same Material, with Half the Labor, and Showing How to Lay Out Stairs of all Kinds. By R. J. SHERRATT. Folio. . . . $2.50

SYME.—Outlines of an Industrial Science.
By DAVID SYME. 12mo. $2.00

TABLES SHOWING THE WEIGHT OF ROUND, SQUARE, AND FLAT BAR IRON, STEEL, ETC.,
By Measurement. Cloth 63

THALLNER.—Tool-Steel:
A Concise Handbook on Tool-Steel in General. Its Treatment in the Operations of Forging, Annealing, Hardening, Tempering, etc., and the Appliances Therefor. By OTTO THALLNER, Manager in Chief of the Tool-Steel Works, Bismarckhütte, Germany. From the German by WILLIAM T. BRANNT. Illustrated by 69 engravings. 194 pages. 8vo. 1902. . . . . $2.00

TEMPLETON.—The Practical Examinator on Steam and the Steam-Engine:
With Instructive References relative thereto, arranged for the Use of Engineers, Students, and others. By WILLIAM TEMPLETON, Engineer. 12mo. $1.00

THAUSING.—The Theory and Practice of the Preparation of Malt and the Fabrication of Beer:
With especial reference to the Vienna Process of Brewing. Elaborated from personal experience by JULIUS E. THAUSING, Professor at the School for Brewers, and at the Agricultural Institute, Mödling, near Vienna. Translated from the German by WILLIAM T. BRANNT. Thoroughly and elaborately edited, with much American matter, and according to the latest and most Scientific Practice, by A. SCHWARZ and DR. A. H. BAUER. Illustrated by 140 Engravings. 8vo., 815 pages $10.00

THOMPSON.—Political Economy. With Especial Reference to the Industrial History of Nations:
By ROBERT E. THOMPSON, M. A., Professor of Social Science in the University of Pennsylvania. 12mo. $1.50

THOMSON.—Freight Charges Calculator:
By ANDREW THOMSON, Freight Agent. 24mo. . . . $1.25

TURNER'S (THE) COMPANION:
Containing Instructions in Concentric, Elliptic, and Eccentric Turning; also various Plates of Chucks, Tools, and Instruments; and Directions for using the Eccentric Cutter, Drill, Vertical Cutter, and Circular Rest; with Patterns and Instructions for working them. 12mo. $1.00

TURNING: Specimens of Fancy Turning Executed on the Hand or Foot-Lathe:
With Geometric, Oval, and Eccentric Chucks, and Elliptical Cutting Frame. By an Amateur. Illustrated by 30 exquisite Photographs. 4to. . . . . (Scarce.)

VAILE.—Galvanized-Iron Cornice-Worker's Manual:
Containing Instructions in Laying out the Different Mitres, and Making Patterns for all kinds of Plain and Circular Work. Also, Tables of Weights, Areas and Circumferences of Circles, and other Matter calculated to Benefit the Trade. By CHARLES A. VAILE. Illustrated by twenty-one plates. 4to. . . . . (Scarce.)

VILLE.—On Artificial Manures:
Their Chemical Selection and Scientific Application to Agriculture. A series of Lectures given at the Experimental Farm at Vincennes, during 1867 and 1874–75. By M. GEORGES VILLE. Translated and Edited by WILLIAM CROOKES, F. R. S. Illustrated by thirty-one engravings. 8vo., 450 pages $6.00

VILLE.—The School of Chemical Manures:
Or, Elementary Principles in the Use of Fertilizing Agents. From the French of M. GEO. VILLE, by A. A. FESQUET, Chemist and Engineer. With Illustrations. 12mo. $1.25

VOGDES.—The Architect's and Builder's Pocket-Companion and Price-Book:
Consisting of a Short but Comprehensive Epitome of Decimals, Duodecimals, Geometry and Mensuration; with Tables of United States Measures, Sizes, Weights, Strengths, etc., of Iron, Wood, Stone, Brick, Cement and Concretes, Quantities of Materials in given Sizes and Dimensions of Wood, Brick and Stone; and full and complete Bills of Prices for Carpenter's Work and Painting; also, Rules for Computing and Valuing Brick and Brick Work, Stone Work, Painting, Plastering, with a Vocabulary of Technical Terms, etc. By FRANK W. VOGDES, Architect, Indianapolis, Ind. Enlarged, revised, and corrected. In one volume, 368 pages, full-bound, pocket-book form, gilt edges $2.00
Cloth 1.50

VAN CLEVE.—The English and American Mechanic:
Comprising a Collection of Over Three Thousand Receipts, Rules, and Tables, designed for the Use of every Mechanic and Manufacturer. By B. FRANK VAN CLEVE. Illustrated. 500 pp. 12mo. $2.00

VAN DER BURG.—School of Painting for the Imitation of Woods and Marbles:
A Complete, Practical Treatise on the Art and Craft of Graining and Marbling with the Tools and Appliances. 36 plates. Folio, 12 x 20 inches. $10.00

WAHNSCHAFFE.—A Guide to the Scientific Examination of Soils:
Comprising Select Methods of Mechanical and Chemical Analysis and Physical Investigation. Translated from the German of Dr. F. WAHNSCHAFFE. With additions by WILLIAM T. BRANNT. Illustrated by 25 engravings. 12mo. 177 pages . . . $1.50

WALTON.—Coal-Mining Described and Illustrated:
By THOMAS H. WALTON, Mining Engineer. Illustrated by 24 large and elaborate Plates, after Actual Workings and Apparatus. $5.00

WARE.—The Sugar Beet.

Including a History of the Beet Sugar Industry in Europe, Varieties of the Sugar Beet, Examination, Soils, Tillage, Seeds and Sowing, Yield and Cost of Cultivation, Harvesting, Transportation, Conservation, Feeding Qualities of the Beet and of the Pulp, etc. By LEWIS S. WARE, C. E., M. E. Illustrated by ninety engravings. 8vo. $4.00

WARN.—The Sheet-Metal Worker's Instructor:

For Zinc, Sheet-Iron, Copper, and Tin-Plate Workers, etc. Containing a selection of Geometrical Problems; also, Practical and Simple Rules for Describing the various Patterns required in the different branches of the above Trades. By REUBEN H. WARN, Practical Tin-Plate Worker. To which is added an Appendix, containing Instructions for Boiler-Making, Mensuration of Surfaces and Solids, Rules for Calculating the Weights of different Figures of Iron and Steel, Tables of the Weights of Iron, Steel, etc. Illustrated by thirty-two Plates and thirty-seven Wood Engravings. 8vo. . $3.00

WARNER.—New Theorems, Tables, and Diagrams, for the Computation of Earth-work:

Designed for the use of Engineers in Preliminary and Final Estimates, of Students in Engineering, and of Contractors and other non-professional Computers. In two parts, with an Appendix. Part I. A Practical Treatise; Part II. A Theoretical Treatise, and the Appendix, Containing Notes to the Rules and Examples of Part I.; Explanations of the Construction of Scales, Tables, and Diagrams, and a Treatise upon Equivalent Square Bases and Equivalent Level Heights By JOHN WARNER, A. M., Mining and Mechanical Engineer. Illustrated by 14 Plates 8vo. $3.00

WILSON.—Carpentry and Joinery:

By JOHN WILSON, Lecturer on Building Construction, Carpentry and Joinery, etc., in the Manchester Technical School. Third Edition, with 65 full-page plates, in flexible cover, oblong. . . (Scarce.)

WATSON.—A Manual of the Hand-Lathe:

Comprising Concise Directions for Working Metals of all kinds, Ivory, Bone, and Precious Woods; Dyeing, Coloring, and French Polishing; Inlaying by Veneers, and various methods practised to produce Elaborate work with Dispatch, and at Small Expense. By EGBERT P. WATSON, Author of "The Modern Practice of American Machinists and Engineers." Illustrated by 78 engravings. $1.50

WATSON.—The Modern Practice of American Machinists and Engineers:

Including the Construction, Application, and Use of Drills, Lathe Tools, Cutters for Boring Cylinders, and Hollow-work generally, with the most Econonical Speed for the same; the Results verified by Actual Practice at the Lathe, the Vise, and on the floor. Together

with Workshop Management, Economy of Manufacture, the Steam Engine, Boilers, Gears, Belting, etc., etc. By EGBERT P. WATSON. Illustrated by eighty-six engravings. 12mo. . . . $2.50

WATT.—The Art of Soap Making:

A Practical Hand-Book of the Manufacture of Hard and Soft Soaps, Toilet Soaps, etc. Fifth Edition, Revised, to which is added an Appendix on Modern Candle Making. By ALEXANDER WATT. Ill. 12mo. $3.00

WEATHERLY.—Treatise on the Art of Boiling Sugar, Crystallizing, Lozenge-making, Comfits, Gum Goods,

And other processes for Confectionery, including Methods for Manufacturing every Description of Raw and Refined Sugar Goods. A New and Enlarged Edition, with an Appendix on Cocoa, Chocolate, Chocolate Confections, etc. 196 pages, 12mo. (1903) . $1.50

WILL.—Tables of Qualitative Chemical Analysis:

With an Introductory Chapter on the Course of Analysis. By Professor HEINRICH WILL, of Giessen, Germany. Third American, from the eleventh German edition. Edited by CHARLES F. HIMES, Ph. D., Professor of Natural Science, Dickinson College, Carlisle, Pa. 8vo. $1.50

WILLIAMS.—On Heat and Steam:

Embracing New Views of Vaporization, Condensation and Explosion. By CHARLES WYE WILLIAMS, A. I. C. E. Illustrated. 8vo. $2.50

WILSON.—First Principles of Political Economy:

With Reference to Statesmanship and the Progress of Civilization. By Professor W. D. WILSON, of the Cornell University. A new and revised edition. 12mo. $1.50

WILSON.—The Practical Tool-Maker and Designer:

A Treatise upon the Designing of Tools and Fixtures for Machine Tools and Metal Working Machinery, Comprising Modern Examples of Machines with Fundamental Designs for Tools for the Actual Production of the work; Together with Special Reference to a Set of Tools for Machining the Various Parts of a Bicycle. Illustrated by 189 engravings. 1898. . . . . $2.50

CONTENTS: Introductory. Chapter I. Modern Tool Room and Equipment. II. Files, Their Use and Abuse. III. Steel and Tempering. IV. Making Jigs. V. Milling Machine Fixtures. VI. Tools and Fixtures for Screw Machines. VII. Broaching. VIII. Punches and Dies for Cutting and Drop Press. IX. Tools for Hollow-Ware. X. Embossing: Metal, Coin, and Stamped Sheet-Metal Ornaments. XI. Drop Forging. XII. Solid Drawn Shells or Ferrules; Cupping or Cutting, and Drawing; Breaking Down Shells. XIII. Annealing, Pickling, and Cleaning, XIV. Tools for Draw Bench. XV. Cutting and Assembling Pieces by Means of Ratchet Dial Plates at One Operation. XVI. The Header. XVII. Tools for Fox Lathe. XVIII. Suggestions for a Set of Tools for Machining the Various Parts of a Bicycle. XIX. The Plater's Dynamo. XX. Conclusion—With a Few Random Ideas. Appendix. Index.

WOODS.—Compound Locomotives:

By ARTHUR TANNATT WOODS. Second edition, revised and enlarged by DAVID LEONARD BARNES, A. M., C. E. 8vo. 330 pp. $3.00

WOHLER.—A Hand-Book of Mineral Analysis:

By F. WÖHLER, Professor of Chemistry in the University of Göttingen. Edited by HENRY B. NASON, Professor of Chemistry in the Renssalaer Polytechnic Institute, Troy, New York. Illustrated. 12mo. $2.50

WORSSAM.—On Mechanical Saws:

From the Transactions of the Society of Engineers, 1869. By S. W. WORSSAM, JR. Illustrated by eighteen large plates. 8vo. $1.50

RECENT ADDITIONS.

BRANNT.—Varnishes, Lacquers, Printing Inks and Sealing-Waxes:

Their Raw Materials and their Manufacture, to which is added the Art of Varnishing and Lacquering, including the Preparation of Putties and of Stains for Wood, Ivory, Bone, Horn, and Leather. By WILLIAM T. BRANNT. Illustrated by 39 Engravings, 338 pages. 12mo. $3.00

BRANNT—The Practical Scourer and Garment Dyer:

Comprising Dry or Chemical Cleaning; the Art of Removing Stains; Fine Washing; Bleaching and Dyeing of Straw Hats, Gloves, and Feathers of all kinds; Dyeing of Worn Clothes of all fabrics, including Mixed Goods, by One Dip; and the Manufacture of Soaps and Fluids for Cleansing Purposes. Edited by WILLIAM T. BRANNT, Editor of "The Techno-Chemical Receipt Book." Illustrated. 203 pages. 12mo. $2.00

BRANNT.—Petroleum.

Its History, Origin, Occurrence, Production, Physical and Chemical Constitution, Technology, Examination and Uses; Together with the Occurrenee and Uses of Natural Gas. Edited chiefly from the German of Prof. Hans Hoefer and Dr. Alexander Veith, by WM. T. BRANNT. Illustrated by 3 Plates and 284 Engravings. 743 pp. 8vo. $7.50

BRANNT.—A Practical Treatise on the Manufacture of Vinegar and Acetates, Cider, and Fruit-Wines:

Preservation of Fruits and Vegetables by Canning and Evaporation; Preparation of Fruit-Butters, Jellies, Marmalades, Catchups, Pickles, Mustards, etc. Edited from various sources. By WILLIAM T. BRANNT. Illustrated by 79 Engravings. 479 pp. 8vo. $5.00

BRANNT.—The Metal Worker's Handy-Book of Receipts and Processes:

Being a Collection of Chemical Formulas and Practical Manipulations for the working of all Metals; including the Decoration and Beautifying of Articles Manufactured therefrom, as well as their Preservation. Edited from various sources. By WILLIAM T. BRANNT. Illustrated. 12mo. $2.50

RICHARDSON.—Practical Blacksmithing:

A Collection of Articles Contributed at Different Times by Skilled Workmen to the columns of "The Blacksmith and Wheelwright," and Covering nearly the Whole Range of Blacksmithing, from the Simplest Job of Work to some of the Most Complex Forgings. Compiled and Edited by M. T. RICHARDSON.

Vol. I. 210 Illustrations. 224 pages. 12mo. . . $1.00
Vol. II. 230 Illustrations. 262 pages. 12mo. . . $1.00
Vol. III. 390 Illustrations. 307 pages. 12mo. . . $1.00
Vol. IV. 226 Illustrations. 276 pages. 12mo. . . $1.00

RICHARDSON.—The Practical Horseshoer:

Being a Collection of Articles on Horseshoeing in all its Branches which have appeared from time to time in the columns of "The Blacksmith and Wheelwright," etc. Compiled and edited by M. T. RICHARDSON. 174 illustrations. $1.00

ROPER.—Instructions and Suggestions for Engineers and Firemen:

By STEPHEN ROPER, Engineer. 18mo. Morocco . $2.00

ROPER.—The Steam Boiler: Its Care and Management:

By STEPHEN ROPER, Engineer. 12mo., tuck, gilt edges. $2.00

ROPER.—The Young Engineer's Own Book:

Containing an Explanation of the Principle and Theories on which the Steam Engine as a Prime Mover is Based. By STEPHEN ROPER, Engineer. 160 illustrations, 363 pages. 18mo., tuck . $2.50

ROSE.—Modern Steam-Engines:

An Elementary Treatise upon the Steam-Engine, written in Plain language; for Use in the Workshop as well as in the Drawing Office. Giving Full Explanations of the Construction of Modern Steam-Engines: Including Diagrams showing their Actual operation. Together with Complete but Simple Explanations of the operations of Various Kinds of Valves, Valve Motions, and Link Motions, etc., thereby Enabling the Ordinary Engineer to clearly Understand the Principles Involved in their Construction and Use, and to Plot out their Movements upon the Drawing Board. By JOSHUA ROSE, M. E. Illustrated by 422 engravings. Revised. 358 pp. . . $6.00

ROSE.—Steam Boilers:

A Practical Treatise on Boiler Construction and Examination, for the Use of Practical Boiler Makers, Boiler Users, and Inspectors; and embracing in plain figures all the calculations necessary in Designing or Classifying Steam Boilers. By JOSHUA ROSE, M. E. Illustrated by 73 engravings. 250 pages. 8vo. $2.50

SCHRIBER.—The Complete Carriage and Wagon Painter:

A Concise Compendium of the Art of Painting Carriages, Wagons, and Sleighs, embracing Full Directions in all the Various Branches, including Lettering, Scrolling, Ornamenting, Striping, Varnishing, and Coloring, with numerous Recipes for Mixing Colors. 73 Illustrations. 177 pp. 12mo. $1.00

DEITE.—A Practical Treatise on the Manufacture of Perfumery:

Comprising directions for making all kinds of Perfumes, Sachet Powders, Fumigating Materials, Dentifrices, Cosmetics, etc., with a full account of the Volatile Oils, Balsams, Resins, and other Natural and Artificial Perfume-substances, including the Manufacture of Fruit Ethers, and tests of their purity. By Dr. C. DEITE, assisted by L. BORCHERT, F. EICHBAUM, E. KUGLER, H. TOEFFNER, and other experts. From the German, by WM. T. BRANNT. 28 Engravings. 358 pages. 8vo. $3.00

EDWARDS.—American Marine Engineer, Theoretical and Practical:

With Examples of the latest and most approved American Practice. By EMORY EDWARDS. 85 illustrations. 12mo. . . $2.50

EDWARDS.—900 Examination Questions and Answers:

For Engineers and Firemen (Land and Marine) who desire to obtain a United States Government or State License. Pocket-book form, gilt edge $1.50

FLEMMING.—Practical Tanning:

A Handbook of Modern Processes, Receipts, and Suggestions for the Treatment of Hides, Skins, and Pelts of Every Description. By Lewis A. Flemming. American Tanner. 472 pp. 8vo. (1903) $4.00.

POSSELT.—The Jacquard Machine Analysed and Explained:

With an Appendix on the Preparation of Jacquard Cards, and Practical Hints to Learners of Jacquard Designing. By E. A. POSSELT. With 230 illustrations and numerous diagrams. 127 pp. 4to. $3.00

POSSELT.—Recent Improvements in Textile Machinery, Part III:

Processes Required for Converting Wool, Cotton, Silk, from Fibre to Finished Fabric, Covering both Woven and Knit Goods; Construction of the most Modern Improvements in Preparatory Machinery, Carding, Combing, Drawing, and Spinning Machinery, Winding, Warping, Slashing Machinery Looms, Machinery for Knit Goods, Dye Stuffs, Chemicals, Soaps, Latest Improved Accessories Relating to Construction and Equipment of Modern Textile Manufacturing Plants. By E. A. POSSELT. Completely Illustrated. 4to. $7.50

RICH.—Artistic Horse-Shoeing:

A Practical and Scientific Treatise, giving Improved Methods of Shoeing, with Special Directions for Shaping Shoes to Cure Different Diseases of the Foot, and for the Correction of Faulty Action in Trotters. By GEORGE E. RICH. 62 Illustrations. 153 pages. 12mo $1.00

LIBRARY OF CONGRESS
0 017 107 638 9